

AN INTERACTIVE APPROACH TO  
CLIMATIC AND MICRO-CLIMATIC DESIGN

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Declaration

I certify that this thesis is my own original work and that the work it contains, without direct references, has been composed by myself.

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I am indebted to my wife who shared with me critical moments, for her support, encouragement, and understanding. Finally, I dedicate this thesis to my parents, to whom the thesis owes more than can ever be expressed.

ABSTRACT

This thesis establishes the principles of an interactive approach to the climatic and micro-climatic design of buildings, and develops the structure of an interactive design process for the application of the approach.

A critical analysis of three well-known methods of climatic design is given. This leads to a description of the structure of what may be called the 'conventional' climatic design process. It is a linear process that is not aimed at designing the building on the basis of knowledge of the micro-climate it gives rise to.

Buildings exist within, and function in relation to, the micro-climate which they produce in interaction with their surroundings. They do not, as the conventional approach appears to assume, operate directly in the climate of the town or region. The relevant values of climatic variables for use in design are those of the building's micro-climate. The relationship between climate, micro-climate, indoor climate, and building is structurally analysed, and on the basis of this analysis the principles of an interactive approach to climatic design are proposed.

These principles are then used to formulate a two-stage climatic design process in which the form of the building evolves gradually, by successive approximation. This means first determining the form which (in synthesis with other design requirements) would lead to a satisfactory micro-climate. /

micro-climate. Constructional, structural, and services designs are then based upon knowledge of the micro-climate. The process can be iterated; but to avoid reiteration and to guide the decision-making process, some logical simplifications of building/environment interaction concerning the prediction of building performance are introduced.

Some examples of traditional built forms and settlement structures, together with examples of modern practice are analysed from the point of view of the building's micro-climate. A comparison is made between traditional and contemporary approaches to illustrate their relations to the interactive approach proposed by this thesis.

A brief survey of available micro-climatic prediction and evaluation techniques is included in a discussion of the practical application of the proposed approach. Emphasis is given to computer-based techniques which can be of particular advantage to micro-climatic research and design.

CONTENTSpage no

ACKNOWLEDGEMENTS	.. .. .	iii
ABSTRACT	.. .. .	iv
GENERAL INTRODUCTION		1.
PART I:	THE CLIMATIC DESIGN OF BUILDINGS - Description and Analysis of the Conventional Approach	8.
CHAPTER I:	<u>CONCEPTS OF BUILDING CLIMATOLOGY AND THEIR RELEVANCE TO THE CLIMATIC DESIGN OF BUILDINGS</u>	9.
1.	Introduction	10.
2.	The Regional Climate	11.
	2.1 Regional Climate Analysis	13.
3.	The Local Climate	15.
	3.1 The Urban Climate	16.
	3.2 The Site Climate	22.
4.	The Building's Microclimate	24.
5.	Summary and Conclusions	28.
CHAPTER II:	<u>ANALYTICAL REVIEW OF THE CONVENTIONAL APPROACH TO THE CLIMATIC DESIGN OF BUILDINGS</u>	30.
1.	Introduction	31.
2.	Thermal Comfort and Climatic Design	32.
3.	The Method of Olgyay: The Bioclimatic Approach	34.
	3.1 The Concept of Climate-Balanced Structure	34.
	3.2 The Design Procedure	35.
	3.3 Design Aids	39.
4.	The Method of Givoni	45.
	4.1 Techniques of Indoor Climate Control	45.
	4.2 /	

page no

4.2	Design Aids	46.
4.3	The Structure of the Method	48.
4.4	General Remarks	48.
5.	The Method of Forward Analysis	50.
5.1	The Forward Analysis Stage	53.
5.2	The Plan Development Stage	53.
5.3	The Element Design Stage	56.
5.4	Comments	56.
6.	Deficiencies in the Conventional Approach	57.
7.	The Conventional Climatic Design Process	62.
7.1	The Framework	62.
7.2	The Structure of the Conventional Climatic Design Process	63.
8.	A Suggested Structural Reformation	66.
9.	Summary and Conclusions	69.
CHAPTER III:	<u>MOTIVATIONS FOR AN INTERACTIVE APPROACH TO CLIMATIC DESIGN</u>	71.
1.	Introduction	72.
2.	The Climatological Sheath	72.
3.	The Concept of Climatic Modification	76.
4.	Complex Approaches to the Relationship between Building Performance and Microclimate	78.
5.	Notes on the Relationship between Built Forms and their Microclimates from the point of view of DESIGN	85.
6.	Summary and Conclusions	90.
PART II:	THE DEVELOPMENT OF AN INTERACTIVE APPROACH TO CLIMATIC AND MICRO-CLIMATIC DESIGN	92.
INTRODUCTION TO PART II	.. .. .	93.
CHAPTER IV: /		

CHAPTER IV:	<u>A DESIGN-ORIENTATED ANALYSIS OF THE INTERACTION BETWEEN BUILDINGS AND THEIR ENVIRONMENTS</u>	95.
1.	Introduction	96.
2.	The Structure of the Interaction between Buildings and their Environments	97.
	2.1 Structural Relationships	98.
	2.2 The Model	99.
3.	Development of a Design-Orientated Model of Building/Environment Interactions	102.
	3.1 Structural Distinction	102.
	3.2 Design Requirements of B	104.
	3.3 Building/Environment Model of Interaction from the point of view of DESIGN	106.
4.	The Building/Environment System of Interaction	107.
	4.1 The Phenomenon of Multiple Modification	109.
	4.2 Building/Environment System of Interaction	113.
	4.2.1 The System	115.
5.	The 'Enhancement' of the Building's Climatic Modifications	117.
6.	Summary and Conclusions	119.
CHAPTER V:	<u>DEVELOPMENT OF AN INTERACTIVE CLIMATIC DESIGN PROCESS</u>	121.
1.	Introduction	122.
2.	Notes on the Overall Design Process	122.
	2.1 The Vertical Structure	123.
	2.2 The Horizontal Structure	127.
3.	The Conceptual Framework of an Interactive Climatic Design Process	130.
4.	/	

	<u>page no</u>
4. Practical Simplification	133.
4.1 Shape, Fabric, and Building Performance	135.
5. Wind, Sun, and Building Shape	139.
6. The Structure of Interactive Climatic Design Process	143.
7. Summary and Conclusions	150.
CHAPTER VI: <u>EXAMPLES OF INTERACTIVE DESIGN IN TRADITIONAL ARCHITECTURE AND OF PARTIAL APPROACHES IN CONTEMPORARY ARCHITECTURE</u>	152.
1. Introduction	153.
2. The Courtyard House Form	154.
3. Traditional Settlements	160.
3.1 Settlements in Hot-dry Regions	160.
3.2 Settlements in Warm-humid Regions	165.
3.3 Integration in Traditional Settlements	167.
4. Micro-Climatic Designs in Contemporary Architecture	169.
4.1 A Settlement in the Swedish Arctic	169.
4.2 Sea Ranch: A Coastal Development	172.
4.3 Revolutionary Ideas	175.
5. Traditional vs. Contemporary Approaches	179.
6. Summary and Conclusions	181.
PART III: APPRAISAL OF THE INTERACTIVE APPROACH AND SUMMARY OF CONCLUSIONS	183.
CHAPTER VII: <u>ASSESSMENT OF THE PRACTICABILITY OF THE INTERACTIVE APPROACH : Possibilities and Limitations of its Applications</u>	184.
1. Introduction	185.
2. A Pliant Strategy for Micro-climatic Design : Stage 1	186.
3. /	

page no

3.	People and Outdoor Environments	189.
	3.1 Physiological Effects	190.
	3.2 Mechanical Effects	194.
4.	Simulation and Prediction of the Building's Micro-climate	197.
	4.1 Insolation and Shading Pattern of Buildings	197.
	4.2 Wind Flow Around Buildings	201.
5.	The Building and Its Micro-climate: Research and Design	205.
6.	Summary and Conclusions	211.
CHAPTER VIII: <u>SUMMARY OF OVERALL ARGUMENT AND CONCLUSIONS</u>		212.
BIBLIOGRAPHY		219.



## GENERAL INTRODUCTION

Throughout history, man has sought refuge in a shelter to protect himself from the adversities of nature. This need for shelter, except perhaps in the case of cave-dwelling, had to be met by a conscious realisation of a built form which involves at least a minimal knowledge of a building process.

Such knowledge is all-embracing in indigenous and vernacular building traditions, combining the socio-cultural, economic as well as the climatic aspects of shelters and is manifested in typical built forms. The Eskimos' igloo, the courtyard house, the African hut are all manifestations of traditional forms of shelter which display implicit knowledge of a self-organising building process. The tradition itself is presumably a process of slow growth in which 'knowledge' is developed mainly by the means of 'trial-and-error'. Form and function in this process are blended over time to become inseparable in the mind of the builder and are passed on from one generation to another as typical forms.

The lack of technological advancements coupled with meagre resources of energy, forced the reliance on local material and the use of local, perhaps primitive, technologies in developing built forms. But they also forced man to comply with the local natural phenomena of which the climate is a major component. It is, therefore, natural that the climatic adaptation of built forms forms an inseparable part of building /

building traditions.

This is hardly the case with contemporary built forms in to-day's 'developed' societies. Building traditions have been abandoned, to be replaced by scientific design methods which are governed by explicit knowledge developed specifically for the purpose of application. The multi-disciplinary nature of design, however, has often retarded progress by forcing the acceptance of over-simplified and sometimes misleading concepts in order to keep pace with the rapid industrialization and urbanization of the built environment.

The abundant supply of energy and the development of sophisticated systems of heating or air-conditioning, though both are commendable in some respects, encouraged tendencies for man to work against, rather than with, nature and to disregard the importance of the climatic adaptation of built forms. Moreover, the use of such systems has acquired, over time, a social status. Just as the climatic adaptation of traditional built forms is an implicit part of an accepted whole, these systems of artificial control have been accepted as the 'norm' in modern buildings.

The totality of the built environment and its influence on man may be difficult to study and appreciate. But certainly indifference towards nature introduces a great many ecological problems; it also violates the rationale of design which the scientific method has been set up to achieve in the first place.

This /

This thesis draws upon the scientific method to establish an adequate strategy for the climatic adaptation of built forms in view of the limitations of existing approaches. The premise of the study is that buildings should not be thought of as separate from their environments and that one can and should be related to the other through design. This requires the analysis of their interaction and the development of a strategy which would enable the construction of compatible forms.

The task of climatic design can be simply defined as the consideration, at the design stage, of the difference between an existing climate and desired environmental conditions with a view to achieving the latter as an objective of design.

Well known studies in this field (such as Olgyay, 1963; Givoni, 1976; and Koenigsberger et al., 1974; which are analysed in Chapter 2) share a common, 'conventional' approach to climatic design. The approach is structured to deal primarily, and directly with indoor climates by means of the design of building envelopes. The strategy of the approach runs as follows. Information about the existing climate (i.e. the climate which exists before the building) described in terms of the regional or local climate should enable us to determine the expected heating or cooling loads on the building. Knowledge of the climatic performance of buildings, particularly those which relate to heat flow and natural ventilation across the building's envelope, is then used in describing /

describing built forms likely to produce particular indoor climates when exposed to specific conditions of regional or local climates. Several studies (some of which are discussed in Chapter 1) have considered the necessary climatic data and the appropriate form of representing them for use in this connection. Others (see Chapters 2 and 7) have studied the man/environment bioclimatic relationship in order to determine the desired or "comfortable" indoor conditions.

However, a considerable volume of the literature (e.g. Ryd, 1970, 1973; O'Sullivan, 1970; Penwarden and Wise, 1975; discussed in Chapter 3) discusses how built forms modify the climate in their immediate vicinity and produce micro-climates. These micro-climates affect the well-being of people and influence their outdoor activities. The functional use of the outdoor spaces around and between buildings is critically dependent on the micro-climates of such spaces. The micro-climate depends on the design of the built form and the argument is for buildings to be designed so as to improve outdoor environments.

The two groups of studies are aimed at the same thing, the design of the building envelope, though with different objectives in mind. In one case, the design is aimed at effecting the indoor climate of the building and in the other, it is control of the micro-climate which predominates.

However, the micro-climate, produced by the building interacting /

interacting with the existing local climate is in fact the climate in which the building exists and functions. If the micro-climate is nearer than the local climate to conditions required by people it is also nearer than the local climate to the conditions required inside the building. Therefore, designing for 'good' micro-climatic conditions not only improves the quality of external spaces, it also reduces the functional environmental task of the building.

The adequate design of buildings so as to meet the bioclimatic requirements of man has, therefore, two mutually consistent aims: to control the micro-climate of the outdoor spaces around buildings and to control the indoor climate.

This is the basis for what we may call an interactive approach to climatic and micro-climatic design. This study is aimed at establishing the principles of this approach and develops the structure of a design process which would be necessary for realising it.

The thesis is divided into three Parts. Part I is a critical analysis of the literature from the point of view of the concept of building micro-climates. Chapter 1, deals with the climatic concepts which are relevant to the stages of decision-making of the built environment. These include the "regional", "urban", and "site" climates. The emphasis is given to the distinction which is made between these concepts and that of the building's microclimate from the point of view of design. Chapter 2 is an analytical review of /

of three well-known methods of climatic design.

The analysis of the methods enables a description to be made of a common structure underlying the design procedures which the methods introduce. The conclusion is reached that a structural reform of the conventional climatic design process is required; the nature of this reform is also discussed. In Chapter 3 a number of existing studies are described which suggest the need for improving outdoor environments by means of the design of building envelopes.

Part II deals with the theoretical and practical aspects of the proposed interactive approach. Chapter 4 describes the structure of the interaction between the building and its environment in terms of a design-orientated model embodying the structural relationships between the building, its micro-climate, the internal climate, and people. The theory of the interaction is adopted from Wilson, 1973 and Lord and Wilson, 1980, and modified so as to make explicit some inner relationships which clarify the role of the micro-climate in the setting up of the interactive approach at a structural level. A conceptual framework is developed in Chapter 5 and used as a basis for formulating an interactive climatic design process. This process is analogous to embedding the building/environment system of interaction (developed in Chapter 4) in the architectural design process. Analyses are made in Chapter 6 of some examples of built forms which seem to suggest the implicit existence of the interactive approach. Traditional built forms and patterns of settlements, in different climatic regions, /

regions, as well as examples of modern practices are reviewed to illustrate their responsiveness to problems of the micro-climate. A comparison is made between traditional and contemporary approaches which emphasizes the importance of the 'organic' unity of traditional forms as vital to climatic and micro-climatic control of built environments.

Part III is an appraisal of the interactive approach which was proposed in Part II. Chapter 7 deals with the practicability of introducing this approach in the light of available knowledge related to micro-climatic design, and suggests means by which to enhance the application of the approach. Chapter 8 gives a summary of overall argument and conclusions of the thesis.

PART I

THE CLIMATIC DESIGN OF BUILDINGS  
- Description and Analysis of  
the Conventional Approach

Contents:

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|-------------|--|
| Chapter I   | Concepts of Building Climatology<br>and their Relevance to the Climatic<br>Design of Buildings |
| Chapter II  | Analytical Review of the Conventional<br>Approach to the Climatic Design of<br>Buildings       |
| Chapter III | Motivations for an Interactive<br>Approach to Climatic Design                                  |



## CHAPTER I

### CONCEPTS OF BUILDING CLIMATOLOGY AND THEIR RELEVANCE TO THE CLIMATIC DESIGN OF BUILDINGS

#### CONTENTS:

1. INTRODUCTION
2. THE REGIONAL CLIMATE
  - 2.1 Regional Climate Data
3. THE LOCAL CLIMATE
  - 3.1 The Urban Climate
  - 3.2 The Site Climate
4. THE BUILDING'S MICROCLIMATE
5. SUMMARY AND CONCLUSIONS

## 1. INTRODUCTION

The need to develop rational methods for the climatic design of building has led to investigations of the climate/man relationship, in order to define the 'desired' condition of the climate for man; and of the climate/building interaction in order to acquire knowledge of the building's climatic behaviour.

This chapter deals with those concepts of building climatology which are concerned with the description of the climate from the point of view of design. An adequate description of the climate in this respect should satisfy two conditions: it should be representative of the specific climatic condition at hand and it should be presented in a form relevant to application in building design.

Attempts are usually made to resolve the problem of description of the climate by manipulation (largely statistical) of available climatological data, in order to develop so-called "climate design data". Recent research in building climatology, however, regards this problem as part of a larger one concerning the physical interaction between built forms and their microclimates. The answer to the problem of adequate climatic information is to be found in the understanding of this interaction.

The categories of the climate, which are discussed here are the "regional" climate and the "local" climate - the latter includes the "urban" climate and the "site" climate. The /

The description of climate associated with each of these categories includes the size and characteristics of the area it represents, the selection and relative importance of climatic variables in each, and the degree of accuracy achieved in describing the climate.

In addition, and most important, there is the building's microclimate which is strongly influenced by the design of the building itself. This is a fundamentally different kind of concept from those mentioned above. The argument put forward in this study is that, although knowledge of both the site climate and the building's microclimate is necessary to complete the task of climatic design, they are of different significance as far as the design is concerned. The discussion which follows shows that the distinction between the site climate and the building's microclimate is a consequence of the dependence of this microclimate on the design of the building. A sensible approach to climatic design must take this into consideration.

## 2. THE REGIONAL CLIMATE

The Climate is an "abstract concept", best understood in relation to the Weather. The weather is the "momentary state" of the atmospheric elements, i.e. rainfall, air temperature, sunshine, etc., described for a short period of time in the range of a few minutes and up to several hours or a few days. The climate is defined as "generalization or /

or integration" of weather conditions, characteristics of a given region, for an extended period of time (normally in the range of 30 years).

Descriptions of both the weather and the climate develop from the same basic meteorological data. A national network of meteorological stations has two aims (Stringer, 1972b, pp.14-15):

- a) A "synoptic aim" to provide observations for as large an area as possible; such materials are used directly in forecasting weather.
- b) A "climatological aim" to assemble the observed materials over a period of time into climatic data by which to define the climate.

In order to achieve these aims, and for the observations of different stations to be comparable, "standardisation of exposure" is required, which influences the location of the observing stations (as well as the measurement techniques and the timing of observations). The stations, therefore, are deliberately located on sites where local influences on the meteorological phenomena, caused for example by local topography or near-by structures, are kept to a minimum. Locations such as those at airports, in open-air fields, or on top of tall structures are suitable sites for meteorological stations.

The available climatic data, such as those published in national statistical year books or obtained from the meteorological offices of a country, are grouped and analysed to /

to obtain a description of the general "macro" climate of a region, i.e. the 'regional' climate<sup>1</sup>.

## 2.1 Regional Climate Analysis

Climatological data of regional climates are structured to serve general purposes, not necessarily applicable to those of building design. In the last few decades a number of regional climate methods of analysis have developed for the purpose of application in the climatic design of buildings.<sup>2</sup>

Some of these methods (e.g. Olgyay, 1963; Evans, 1980) are concerned with the requirements of climatic design, while others (e.g. ASHRAE, 1966; IHVE, 1970) are more concerned with the use of heating and air conditioning systems in buildings. These methods deal with data of single climatic parameters independently. They rely on graphical techniques to simplify available data, and present them in a form which portrays particular features of the regional climate (see Figs. 1 and 2). The data consist mostly of frequency distributions of mean and extreme values.

Other /

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1. There are five types of stations in a meteorological network: central office, central station, and stations of the first, second and third order. Data of regional climates are provided by central stations; see Conrad and Pollak, 1950.
  2. See Taesler, 1973a, for a comparative study of available methods.



Other methods, such as that of Van Straaten (1967), deal with combinations of values of climatic parameters in order to develop data which can be used directly in connection with "multi-variate" problems. Depending on the climate, a dominant parameter, such as air temperature, is chosen as a "leading parameter", the values of which define typical period(s), within which the values of other parameters are included to complete a "set of related values". This approach has resulted in concepts such as "typical cold" or "typical warm" days (Van Straaten, 1967), or "reference year" or "extreme months" (Anderson et al, 1973).

### 3. THE LOCAL CLIMATE

Embedded in the regional climate are local climates, known in "terrain climatology" as "topoclimates" (Geiger, 1965, rev. ed.; 1969). Local climates develop in specific places due to the combined effect of distinctive features of terrain on the meteorological phenomena of their vicinity. Examples are the climate of "slopes" or the climate of "valleys", which develop as a result of the aerodynamic characteristics of the land forms and the thermal properties of their land cover.

The influence of the factors affecting the local climate depends on the scale of the area being considered. In general, these factors include topography, the type of soil and vegetation cover, built forms, and the presence or /



or proximity to water bodies. Available knowledge of local climates, and the understanding of their causative relationships have been structured in the literature of building climatology (e.g. Shellard, 1965; Lacy, 1977) with the aim of directing attention to the generality of regional climate data, and provide materials for consideration in the climatic planning and design of buildings.

For example, Lawson (1968) distinguished between three types of the aerodynamic roughness of terrain - open country, rough wooded country, and urban centre, in terms of the wind velocity gradient in each case. (see Fig. 3). Evans (1980) summarises the variations of climatic variables with respect to, among other things, the increase in altitude (Table 1) and distance from the coast (Table 2).

### 3.1 The Urban Climate

The term "urban climate" is used to describe the climatic features peculiar to the city, due to its urban influence. According to Chandler (1965, p.20), there are three main determinants of the city climate:

- a) The general climate of the region.
- b) The modifying influences of the local morphology of the city site.
- c) The "self-induced" modifications of the city, i.e. the urban influence, which includes modifications by the thermal and aerodynamic properties of built forms, /



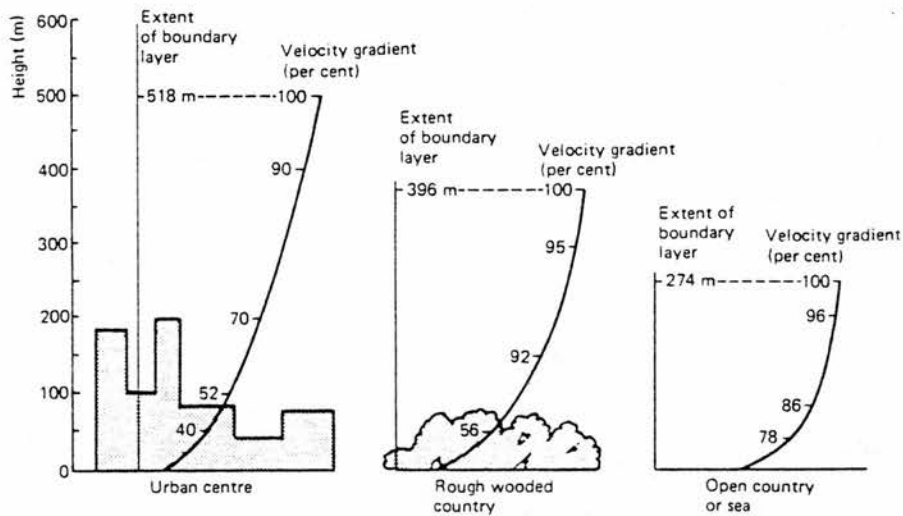


Fig.3: Profiles of mean velocity (%) over level terrains of differing roughness (adapted from: Lawson, 1968, p. 1422, and cited in Markus and Morris, 1980, p.208)

Climatic variable	Effect of 100m increase in altitude
Annual mean temperature	0.5 deg C decrease (increasing to 1.0 deg C in high latitudes)
Range between hottest and coldest mean monthly temperature	0.25 deg C decrease
Range between mean daily maximum and minimum temperature	Significant increase
Relative humidity	Slight increase
Solar radiation	0.25% increase (increasing to 0.45% in high latitudes)
Total annual precipitation	Up to 100mm increase, but highly dependent on topography and wind direction
Wind speeds	Significant increase, unless sheltered by topography

Note: The values given are indicative only and may not apply in all situations.

Climatic variable	Effect of 10km distance from the coast
Diurnal temperature range	2-4 deg C increase
Annual temperature range	3-6 deg C increase (greater in dry climates, less in humid climates)
Relative humidity	Usually lower — little difference in humid regions, but more marked in dry regions or dry seasons
Cloud cover	Usually less
Radiation	Greater due to lower humidity and cloud cover
Wind	Sea breezes cease; 10-30% drop in on-shore winds (depending on topography)
Rainfall	Usually less — however some coastal locations may remain relatively dry while rainfall increases with increasing distance inland up to 5-10km before decreasing at greater distances

Note: A flat coastal plain is assumed.

Table 2: Variation in climate between coastal and inland locations. (from: Evans, 1980, p.13)

Table 1: Variation in climate with increasing altitude (from: Evans, 1980, p. 13)

forms, the impervious layer of pavements and roads, as well as the seepage of heat and dispersal of impurities in city air, caused by human activities such as industry, heating of buildings, use of motor vehicles, etc.

In comparison with the regional climate, the influence of a city results in, among other things, an increase in air temperature known as the "heat island" effect (O'Sullivan, 1970), a reduction in mean wind speed, a reduction in the relative humidity of the air, and air pollution and fog formation (see Table 3). Landsberg (1970b) prepares a list showing average changes of the variables of urban climate in relative terms (see Table 4).

There are considerable difficulties in developing quantitative measures of the relationship between aspects of town planning such as density or height of buildings, and changes of the urban climate. Such difficulties are due partly to the complexity of the modifications which underline the change, and partially to the difficulty of isolating the urban influence per se from other modifying influences.<sup>1</sup>

Based /

- 
1. The reason for the difficulty of isolating the urban influence is linked to the method of investigation formally used in studying the urban climate, which relies on simultaneous meteorological observations in and outside the city so as to identify differences between the city climate and the climate of surrounding rural areas; see Geiger, 1965, p.489.

Element	Town environment as compared with rural
Contaminants condensation nuclei and particulates gaseous admixtures	10 times more 5 to 25 times more
Cloudiness average cloud cover fog in summer fog in winter	5 to 10 per cent more 30 per cent more 100 per cent more
Precipitation total amount days with less than 5 mm snowfall	5 to 10 per cent more 10 per cent more 5 per cent less
Relative humidity in winter in summer	2 per cent less 8 per cent less
Radiation global solar radiation ultra-violet in winter ultra-violet in summer duration of bright sunshine	15 to 20 per cent less 30 per cent less 5 per cent less 5 to 15 per cent less
Temperature annual mean average winter minima heating degree days	0.5 to 1.0 deg C more 1 to 2 deg C more 10 per cent less
Wind speed annual mean extreme gusts number of calms	20 to 30 per cent less 20 to 20 per cent less 5 to 20 per cent more

Table 4: Average changes in climatic elements caused by urbanization, (from: Landsberg, 1970 b, p.372).

Elements of the Urban Influence	"Static Elements"			"City Energies"	
	Heat absorption and storage qualities of construction material	Impervious material	Aerodynamic roughness of buildings	Heat produced in city	Dispensing of impurities
Factors of urban climate					
Increased temperature (heat-island effect)					
Reduced wind speed					
Reduced relative humidity					
Air pollution & fog formation					

Table 3: Basic causative relationships of urban climate (based on Kratzer, 1956, Chandler, 1965, O'Sullivan, 1970, and Landsberg, 1970 b).

Based on available knowledge of urban climates, and knowledge of the interaction between built forms and their environments, Givoni (1973, p.1) gives a general account of aspects of town planning affecting the relationship between regional and urban climates. These include

- " - The location of the town in the region.
- The size and density of the built-up area.
- Width of the streets and their relation to the prevailing winds and sun position.
- The height of the buildings.
- The nature and albedo of the external surface of the urban area.
- The total area and distribution of green areas.
- Some details of the design of the buildings."

Although features of the urban climate are studied as a "unified whole" in terms of urban/rural climatic differences, it is the cumulative effect of small-scale climatic modifications which are of special significance to the planning and design of built forms. Within the urban climate, "numerous microclimates develop, introduced by different styles and types of buildings and land use" (Landsberg, 1981, p.310). "Each house, factory,...creates its own distinctive microclimatic envelope and these in combination produce a substantial climatic unit - the urban climate" (Chandler, 1965, p.20) (my emphasis).

Kratzer's classification of the city climate (1956,p.2) indicates three stages of modification involved in shaping the urban climate: "a unified whole", "specific parts", and "specific streets". Accordingly, Table 5 illustrates the relevant aspects of decision-making in town planning. This /

Classification of the Urban Climate	Stages of modifications and type of decision-making
<p>1. <u>The city climate as a 'unified whole':</u></p> <p>Knowledge of urban/rural average differences; potential dispersal of air pollution beyond the city boundaries.</p>	<p><u>Site selection of new towns:</u></p> <p>Study of the combined effect of urban influence and influence of local morphology, i.e. topography, proximity to water bodies, etc.</p>
<p>2. <u>The climate of specific parts of the city:</u></p> <p>problems of air pollution and fog formation within the city.</p>	<p><u>Neighbourhood - to - Neighbourhood Relationships:</u></p> <p>Areas of potential air pollution; planning of land-use (industrial vs. residential or recreational; congested vs. non-congested areas; etc.</p>
<p>3. <u>The climate of specific streets:</u></p> <p>Problems of sun, wind, and light in the open spaces of the city</p>	<p><u>Building - to - Building Relationship:</u></p> <p>Orientation, height, spacing between buildings, parallel vs. enclosed layouts, etc.</p>

Table 5: Stages of modification of the urban climate (adapted from: Kratzer, 1956)

This approach to understanding the 'making' of the urban climate is important because it emphasises the importance of microclimatic design, from the point of view of controlling the urban climate.

### 3.2 The Site Climate

The concept of "site climate" recognises the need to study the local climate of the site during the planning and design of built forms. Regional data cannot be expected to provide reliable climatic information for a particular site, but rather the site climate can be studied with the guidance of the regional climate.

The term "site climate" is introduced by Koenigsberger et al (1974, p.31); as in most of the literature, it is employed as a general concept, to be applied, "whatever the size of the project" may be (ibid, p.32). This includes the local climates of large sites, as in the case of developing a whole new town, as well as the climates of the relatively small sites of individual buildings.

Practically, however, there are some aspects which distinguish the local climate of urban sites (i.e. small-scale sites within cities). These aspects, such as the effect of neighbouring buildings, assume dominance at this scale of site climate (Morgan and Wilson, 1974) and must be given prime consideration at the design stage of buildings.

In general, the site climate is studied in the context of two investigations: analysing the local climate of a given site, or, (if possible) searching for a 'site' with potential for advantageous local climate - the latter is a process known as "site selection" (Olgyay, 1963). The literature concentrates on 'site selection', with the aim of/

of demonstrating the modifying influences of local factors (mentioned earlier, such as ground cover, topography, etc.) on the site climate.

Olgyay (1963, pp.44-52) for example, develops a method for site selection based on the amount of solar radiation received on a slope, as a function of the slope's orientation (i.e. its angle of inclination and direction). Evans (1980, pp.54-58) also gives recommendations for site selection in different climatic regions on the basis of large-scale local factors.

However, these are measures which do not relate to the interaction between built forms and their environments; but they can be made to work with (rather than against) this interaction by a proper selection of sites - a negative form of control, so to speak. The problems associated with site climate in urban areas fall in a different category of investigation. Problems of sun and wind are particularly common among urban areas to the extent that site selection is not as critical an issue as site analysis will be.

Basically, there are two approaches for analysing the local climate of an urban site: empirically, by on-site observations, or analytically, by the use of simulation techniques or by deduction from regional data.

On-site observations encounter some technical and practical difficulties which make them hard to obtain in sufficient detail. Normally, the data which are constructed in /



in this way provide relatively short-term records (at most a full yearly cycle) which must be compared with the long term records of the nearest (central) meteorological station in order to display reliable information. On-site observations for even short periods may well be a cumbersome operation in view of the special skill they require.

The analytical approach requires knowledge of the building/environment interaction so that, given the parameters of the surroundings, one can deduce the site climate from the available data of the regional climate. However, with limitations of current knowledge, this has also proven difficult and as Evans (1980, p.13) indicates, "... there are no simple or reliable rules for adjusting climatic data...". A pragmatic approach would, therefore, rely on the simulation techniques currently available (such as the 'wind-tunnel' or 'heliodon') to study the local climates of urban sites.

#### 4. THE BUILDING'S MICROCLIMATE

The 'microclimate' is a general term, used to describe meteorological phenomena at small scales, and contrast them with the phenomena of the macroclimate (i.e. the regional climate) experienced in the national network of meteorological stations. The term has been used variously and there are a number of synonymous terminologies that deal with microclimates.

For example, Shellard (1965) uses the term 'microclimate' to describe the sort of local climates discussed earlier.

Geiger/



Geiger (1965), who contributes much to microclimatology, uses the term to describe the small-scale meteorological phenomena found "in the air layer close to the ground" (about 2m above the ground surface) (ibid, p.2). Geiger groups the synonymous terms, such as 'spot climate', 'habitat climate', 'cryptoclimate', etc., "under the general description of microclimate..." (ibid, p.2).

Research in microclimatology has the aim of explaining what is actually happening in the interaction between microclimates and non-climatic phenomena. Geiger's monograph, which contains numerous investigations, is certainly valuable in this respect. The use of knowledge of microclimates, however, is critical, especially in fields which deal with specific design or operational problems such as in building climatology.

Current research in building climatology is mostly analytical. It focusses on the explanatory approach to microclimatology, and in so doing it succeeds in directing attention to the general nature of regional climate data, the result of which is such a concept as the site climate. Koenigsberger et al (1974, p.31) explain that:

"The term 'site climate' has been chosen deliberately rather than the synonymously-used term 'microclimate'". (my emphasis).

The extent of this descriptive approach to microclimates is limited as far as the design of the built environment is concerned. Climatic knowledge, in general, and knowledge of microclimates in particular, when used in /

in design, has a strong predictive element. It enables the designer to ensure, through a process of prediction, acceptable climatic performance characteristics of built forms.

Gates' definition (Gates, 1972, p.3) of the microclimate is useful in the setting up of a predictive approach in building climatology. He defines the microclimate as "the climate...in the immediate vicinity of an object or organism". Adopting this definition, one can define the building's microclimate as the climate in the immediate vicinity of a building.

This microclimate is strongly influenced by the building itself, and by its surrounding landscape elements and built forms. Gates (ibid, p.155) indicates that: "When man builds a house or a building, the climate outside in the vicinity of the structure is modified immediately". Geiger's remarks (Geiger, 1965, p.480) are:

"Every building constructed displaces the original climate of its site, creating a warm, sunny, and dry climate with a southern exposure on the one hand, and a shady, cold and damp northern climate on the other."

Elements of the landscape such as trees and shrubs modify the wind flow around buildings; the ground cover influences the radiant temperature. In warm climates, asphalt or concrete pavement in the immediate vicinity of a building acts as a "heating-system", radiating heat directly into the building. Little attention, however, is paid to the functional use of landscape elements; as Fitch (cited by Aronin, 1953, p. 146) indicates, "...we use /

use lawns more for what the neighbours will think than for what comfort they might yield us".

We can see, then, that the building exists and functions in a microclimate of its own. Because of the modifying influence of the building on its microclimate, the microclimate carries the consequences of the design of the building. The concept of the building's microclimate recognises, therefore, the interdependency of both the design and the microclimate of a building.

Furthermore, this microclimate prevails as long as the building exists, and when studied at the design stage, it provides information about climatic problems which are linked to the design of the building, and which must be addressed and solved in terms of design. This is a fundamentally different concept from that of the 'site climate', which bears no relation to the design of the building per se, and prevails only until the building exists.

There are two aspects, underlying the functional significance of the building's microclimate:

- a) It affects the functional success of the outdoor spaces around buildings. Often, the visual experience of such spaces dominates their measures of success. A more sensible approach to the design of outdoor spaces would enhance the amenity of the 'outdoors' by relying on a microclimate which facilitates activities, e.g. providing shelter from wind, controlling /

controlling the distribution of solar radiation, etc.

- b) Being the true environment in which the building exists and to which it responds, the microclimate affects the environmental performance of the building. Problems of natural ventilation, or wind-mediated heat loss from buildings, are strongly influenced by the wind flow characteristics around and on the building. Problems of heat gain due to irradiation loads are functions of the building's form in relation to its immediate surroundings. A reliable assessment of building performance during the design stage would necessarily rely on an adequate prediction of the building's microclimate.

## 5. SUMMARY AND CONCLUSIONS

A number of climatic concepts, which relate to the climatic design of buildings have been analysed in this chapter.

The 'regional climate' the 'local climate' and the 'site climate' are concepts which are shown to relate to climatic design in different ways. Some, such as the regional climate, describe the general characteristics of the climate, while others, such as the site climate, would be more specific to the design problem in question.

However, /

However, these concepts are fundamentally different from that of the building's microclimate, i.e. the climate in the immediate vicinity of the building.

The building exists and functions in this micro-climate. The argument is that the building's microclimate affects both people out-of-doors and the performance of the building in the indoor climate. Furthermore, this micro-climate is a response to the design of the building itself. A reliable assessment of building performance would rely on an adequate prediction of the building's microclimate. In the following chapter it is shown that existing procedures of climatic design lack the structure necessary to enable the climatic design of the building to be made on the basis of knowledge of the building's micro-climate.

## CHAPTER II

### ANALYTICAL REVIEW OF THE CONVENTIONAL APPROACH TO THE CLIMATIC DESIGN OF BUILDINGS

#### CONTENTS:

1. INTRODUCTION
2. THERMAL COMFORT AND CLIMATIC DESIGN
3. THE METHOD OF OLGAY: The "Bioclimatic Approach"
  - 3.1 The Concept of "Climate-balanced" Structure
  - 3.2 The Design Procedure
  - 3.3 Design Aids
4. THE METHOD OF GIVONI
  - 4.1 Techniques of Indoor Climate Control
  - 4.2 Design-Aid
  - 4.3 The Structure of The Method
  - 4.4 General Remarks
5. THE METHOD OF "FORWARD-ANALYSIS"
  - 5.1 The Forward Analysis Stage
  - 5.2 The Plan Development Stage
  - 5.3 The Element Design Stage
  - 5.4 Comments
6. DEFICIENCIES IN THE CONVENTIONAL APPROACH
7. THE CONVENTIONAL CLIMATIC DESIGN PROCESS
  - 7.1 The Framework
  - 7.2 The Structure of the Conventional Climatic Design Process
8. A SUGGESTED STRUCTURAL REFORMATION
9. SUMMARY AND CONCLUSIONS

## 1. INTRODUCTION

In this Chapter, the aim is to provide an analytical review of what may be called the 'conventional' approach to the climatic design of buildings. This approach is explored here by analysing three best known methods of climatic design, which provide systematic design procedures.

Two of these methods (Olgyay, 1963; Givoni, 1976 (sec. ed.) ) limit their study to the climatic design per se. This means that the user of the method is required to incorporate the procedure into the overall design process of the building. This last point is included in the framework of the third method (Koenigsberger et al, 1971; Koenigsberger et al, 1974) which projects the climatic design procedure onto the structure of the overall design process.

The dissimilarity between these methods is one of tactical detail, emerging from the particular objective of each, while the structure of the climatic design process underlying all three procedures is the same, originating in each case from the same presumed principles of the climatic behaviour of buildings.

The argument to be made in this thesis is that such a structure does not allow the interaction between the building and its environment to be adequately exploited during the design stage of the building. These methods permit neither prediction nor manipulation of the effect of the building on its microclimate, despite the fact that such an effect is, in some cases, acknowledged and aimed at.

The analytical review which follows illustrates that the building/environment interaction is explored only up to a level thought to fulfil some independently prescribed performance requirements, derived mainly from the study of a particular aspect of man/environment relationships.

## 2. THERMAL COMFORT AND CLIMATIC DESIGN

In general, the climatic design of buildings is strongly influenced by the thermal response of people to the environment, and by the perceived need to control the environmental variables which affect such a response.

Thermal comfort, assumed largely to be the thermal balance between man and his environment, is ultimately subjective matter involving both psychological and physiological factors. While subjective and emotional man/environment relationships are not well understood, it has proved possible to quantify the combined effect of the environmental variables of air temperature, thermal radiation, air velocity and humidity on a human's sensation of thermal comfort. Various thermal indices reflect this process: some, such as the Effective Temperature scale, ET, (ASHRAE, 1966) are derived empirically, on the basis of the sensory response of humans. Others, such as the Standard Effective Temperature, SET, (Gagge et al, 1973) are theoretical, developed on the basis of a heat balance equation, describing man's heat exchange with the environment, and including personal /



personal variables of clothing and activity.<sup>1</sup>

The majority of the thermal indices, particularly those followed by the design methods which will be analysed, were developed originally for the indoor climate, and cover a range of values of the relevant variables that are close to those of indoor conditions. Being concerned mainly with the indoor climate, these methods found it sufficient to equate thermal comfort conditions to 'acceptable' conditions of the environment, to the extent that "designing for a climate" relates wholly to planning the thermal behaviour of buildings, "an operation known as thermal design" (Tropical Advisory Service, 1965/66, p.2).

This should not be taken to suggest that climatic design is, or should be, merely thermal design. In the literature, however, thermal design usually dominates, or at least precedes, the broader functions of climatic design; available climatic design procedures make this quite clear, as will be seen. In most cases, this is done at the expense of other, no less important functions, particularly when considerations are extended to outdoor space.

Problems associated with the mechanical effect of the wind force (Penwarden, 1974) or snow-accumulation on and around buildings can be serious enough, not simply to cause 'discomfort' but to be actually hazardous to survival. These are /

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1. See Chapter 7 for a discussion on the response of people to climate.

are problems of the 'out-of-doors', and must be included within the sphere of influence of the climatic design of buildings. Moreover, the thermal performance of the building, which is the basis of thermal design, is linked to the outdoor conditions immediately outside the building; this is dealt with in subsequent chapters.

### 3. THE METHOD OF OLGYAY: The Bioclimatic Approach

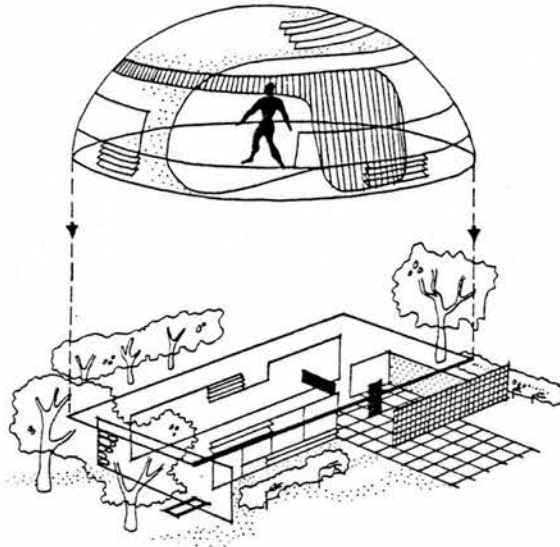
"Design with Climate" (Olgay, 1963) is based on the principle of regional adaptation in architecture. This principle regards the climate as a strong, native element which should motivate variations in the design of buildings in different climatic regions. The effectiveness of Olgay's method for climatic design in exploring this principle can be seen in the light of the results of applying the method in four climatic regions: cool, temperate, hot-arid, and hot-humid regions.<sup>1</sup> The results are contained in a comparative study, developed at different stages of Olgay's book.

#### 3.1 The Concept of Climate-Balanced Structure

As the possibility of completely eliminating dependence on mechanical conditioning of indoor spaces is rare, a "climate-balanced" structure is defined by Olgay (ibid, p.31) as "a structure /

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1. These climatic regions are represented by the climatic data of four major cities in the United States - Minneapolis, the metropolitan area of New York and New Jersey, Phoenix, and Miami - found to be typical of the four regions, respectively; ibid, p.26.



"Theoretical approach to  
balanced shelter."

Fig. 1: (from: Olgyay, 1963,p.15)

structure which maintains conditions near physiological comfort requirements" on a yearly basis. This has led to a seasonal evaluation of human requirements of comfort, taking account of the 'overheated' and the 'underheated' periods that characterize the climate. Consequently, design decisions are taken so as to achieve 'yearly-balanced' indoor conditions.

### 3.2 The Design Procedure

The theory underlying Olgyay's method evolves from a particular approach to the resolution of the multi-disciplinary nature /

nature of climatic control. The problem relates to the "interplay of variables" in the fields of meteorology, biology and physics (or technology), whose consideration should precede the architectural solution. "The sequence for this interplay" and the subsequent structure of the climatic design procedure - i.e. the steps and the activities of the procedure - are defined by Olgyay and summarised here in Table 1 (see also Fig.2). (A design procedure which is similar to Olgyay's, though it deals specifically with the design in the tropics, is introduced by Lippsmeier (1969). Fig. 3 illustrates the order of investigation, but the method is not further described in this thesis because of its structural similarity to Olgyay's approach).

Design Sequence		Design-Related Activities
Climate	step 1:	Survey of the climatic elements at a given location.
Biology	step 2:	Biological evaluation of the climatic impact that describes the corrective measures needed to restore comfort conditions.
Technology	step 3:	Analysis of the performance of building elements with the help of calculative methods, to determine solutions to the climate-comfort problems.
Architecture	step 4:	Combination of the solutions, according to their relative importance, in architectural unity.

Table (1), The design procedure of the 'balanced-structure', (adapted from Olgyay (1963), pp.11-13)

order of investigations

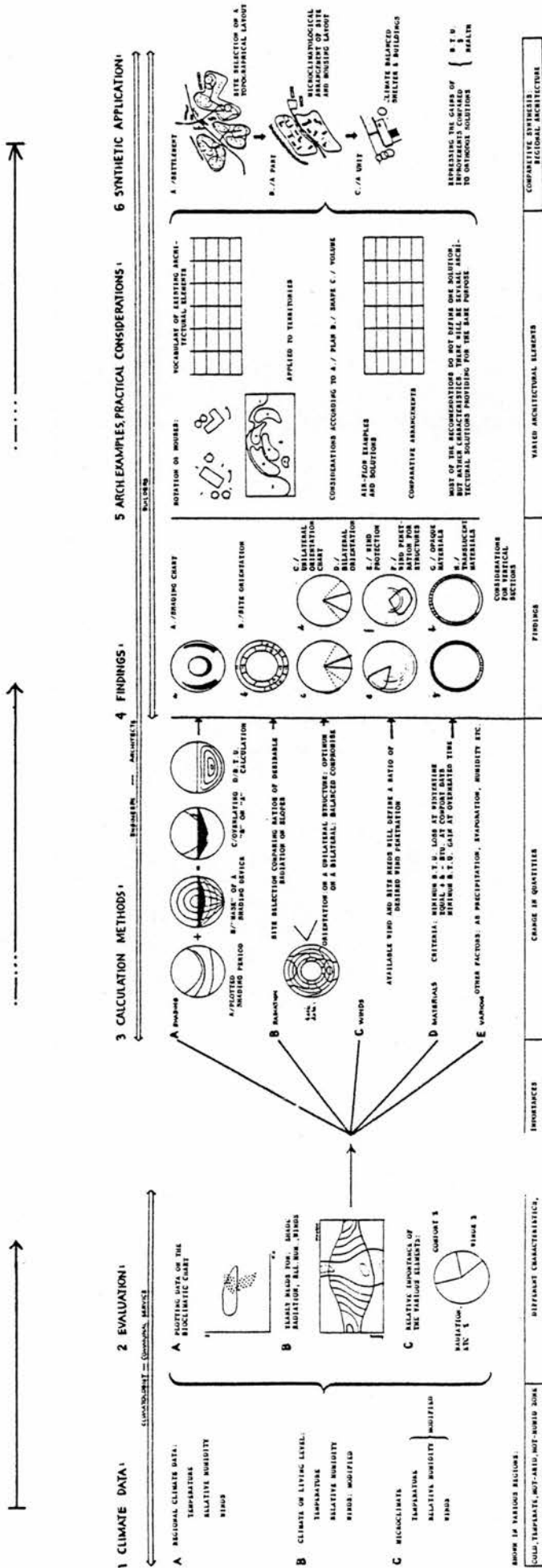


Fig. 2: The structure of Olgyay's method for the climatic design of buildings (from: Olgyay, 1963, pp. 12-13)

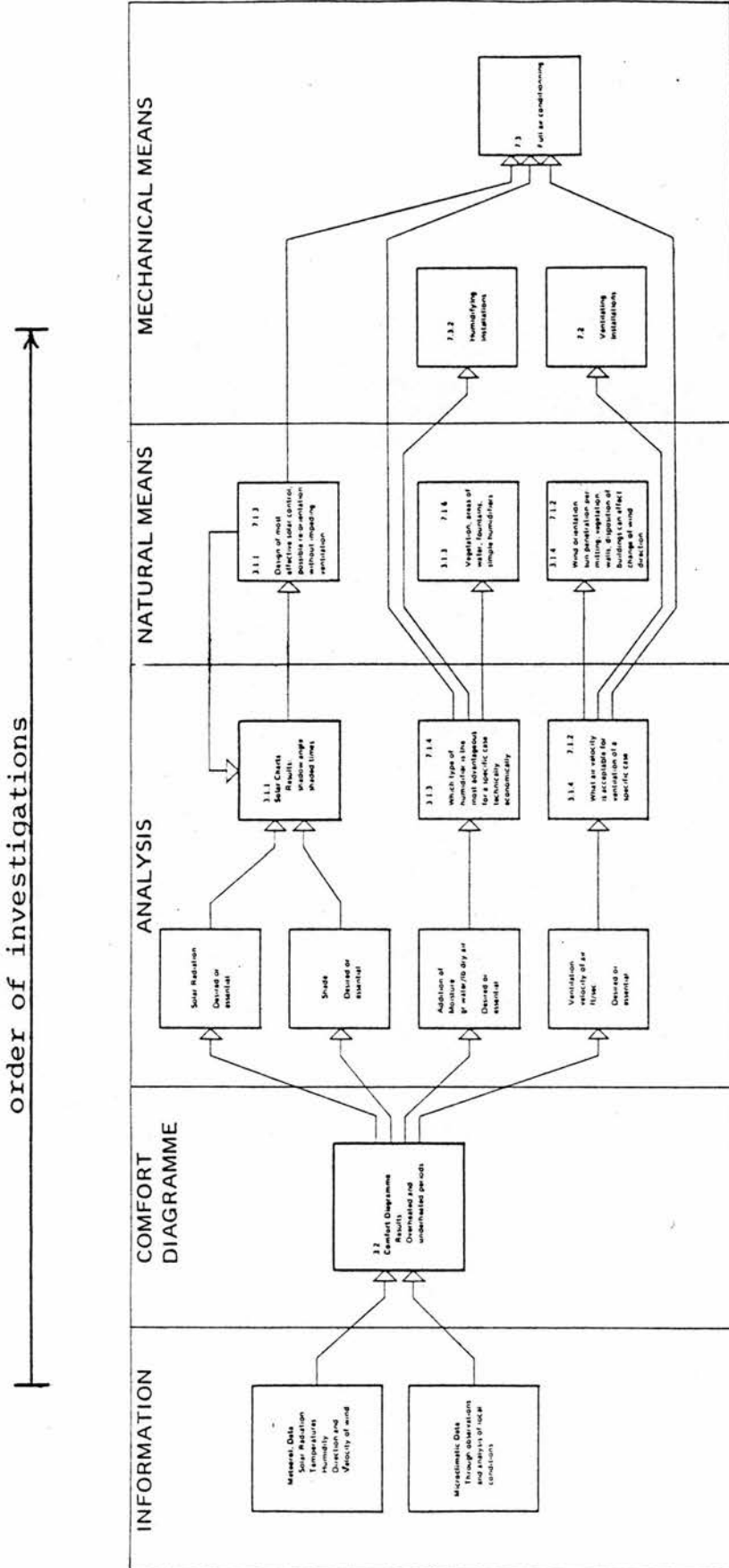


Fig. 3: The structure of Lippesmeier's method for the climatic design in the tropics (from: Lippesmeier, 1969, p.57)

### 3.3 Design-Aids

The four structural steps of this procedure (see Table 1) combine a number of design-related activities. To ease the designer's task; Olgyay exposes them systematically:

3.3.1 The method of the AIA Regional Climate Analysis is adapted for the climatic survey.<sup>1</sup> Since the information it conveys represents the macroclimate, the study takes into consideration two aspects of microclimatology: one deals with the effect of slope-orientation on the amount of solar radiation received on the surface, to be considered during the process of "site selection". The other deals with wind conditions at "living-level" (6 feet above the ground level instead of the standard higher level used for observations by meteorological stations) to be considered during the analysis of acceptable orientations of buildings to the wind.

3.3.2 For the purpose of biological evaluation of the climate, the study introduces the "bioclimatic chart" (see Fig.4). The chart has the double function of climatic analysis and evaluation. It gives the necessary "corrective measures" (of air movement, radiant heating, and evaporative cooling) for the climatic condition whose combination of air temperature and relative humidity are outside the comfort limits. The Effective Temperature scale is relied upon to define the limit conditions of comfort. The results of using the chart are then transferred into a yearly timetable to evaluate the relative importance /

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1. See Figs. 1 and 2, Chapter 1.

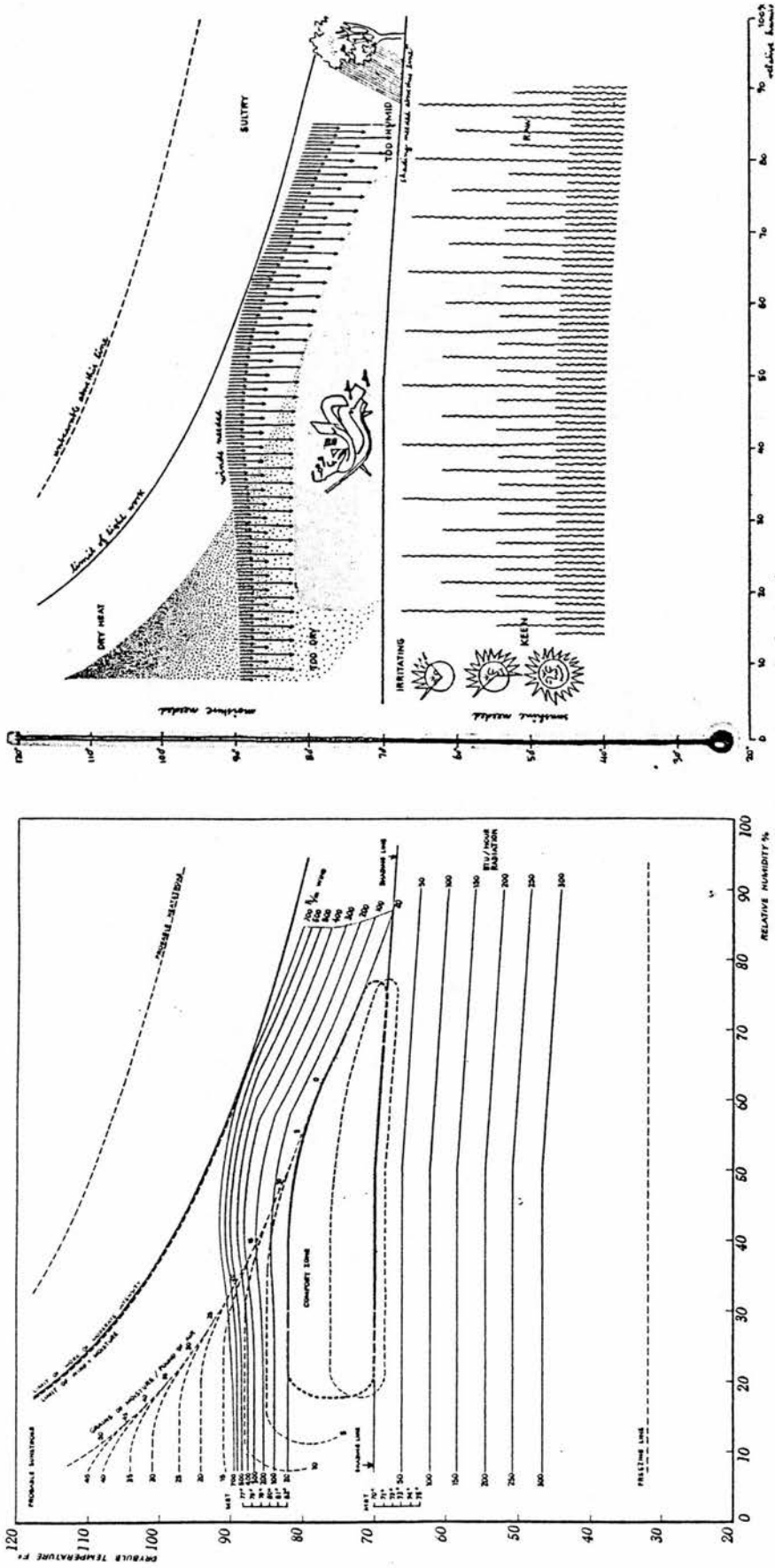


Fig. 4: The "Bioclimatic Chart", and its schematic presentation. (from: Olgyay, 1963, pp. 22-23)



importance of the measures.

3.3.3 In searching for a range of solutions (including an optimum) for building shape, orientation, the design of shading devices, construction materials, etc., the study follows more or less similar strategies. The case for arriving at the "optimum" building shape gives a clear example.

On the basis of knowledge of the combined effect of air temperature and solar radiation, i.e. the "sol-air" temperature, the plan shape of a given built form results in particular external thermal impacts. Such impacts depend, among other things, on the plan elongation with respect to its proportion and orientation. And, from known thermal properties of the form, this gives rise to particular internal thermal impacts. Olgyay's study defines the optimum building shape as that "which loses the minimum amount of outgoing Btu in winter, and accepts the least amount of incoming Btu in summer" (ibid, p.87). Under similar construction characteristics and plan areas, a comparison is made between different arrangements of building shapes to find the optimum (see Fig.5). A heat-flow calculation method, for the assessment of the internal thermal impacts in each case, is described.

The decision-making processes underlying the design of other components of the 'climate-balanced' structure incorporate a similar framework of analysis (supported in each case by a calculational method) and adopt similar criteria for acceptable solutions. Two points should be mentioned here:

a) /

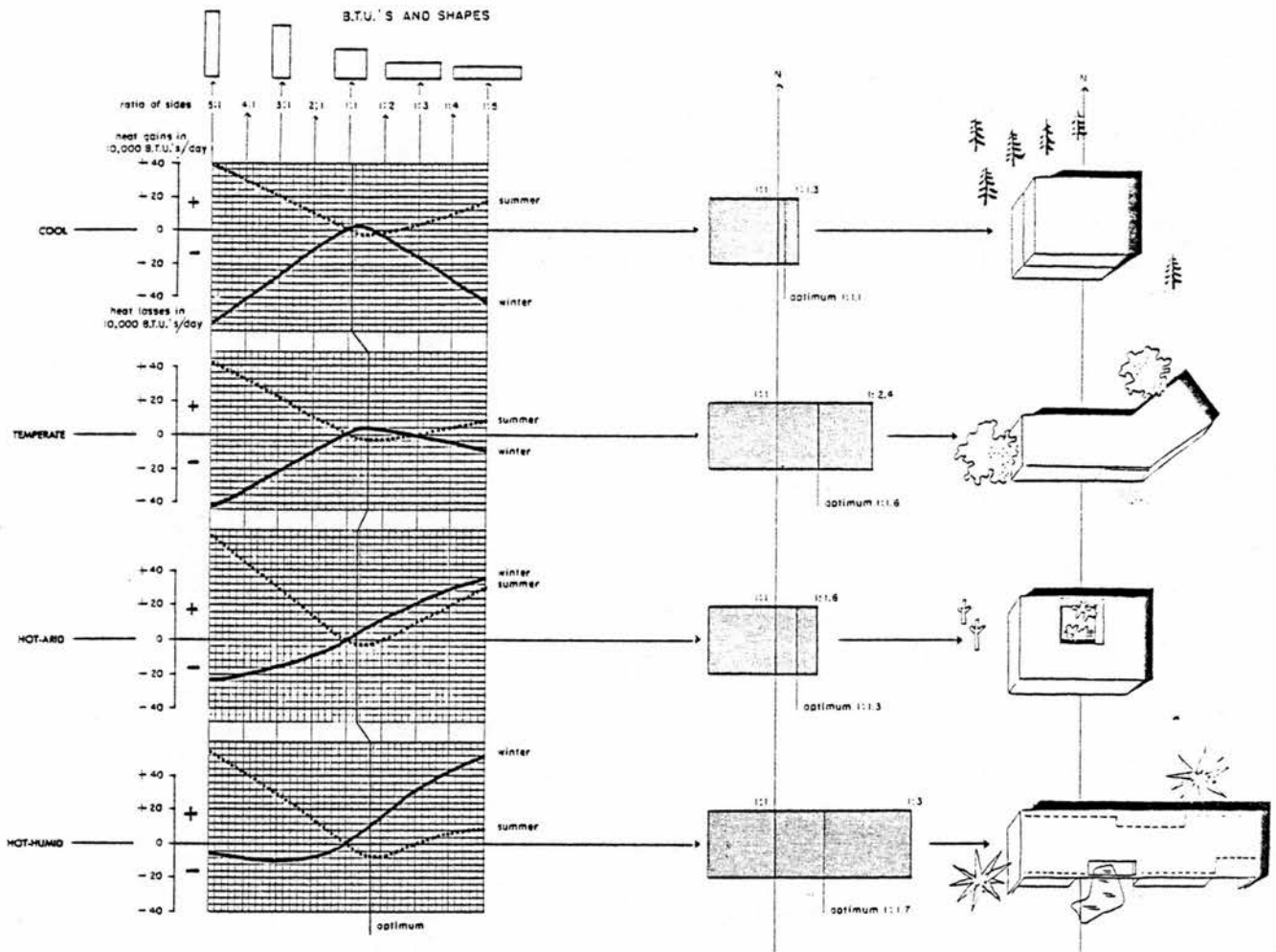


Fig. 5: Basic forms and building shapes in different climatic types as proposed by Olgyay. (from: Olgyay, 1963, p.89)

- a) The criteria for design are confined to the effect of the element concerned on the internal climate. The internal thermal impact (the result of /

of the interaction of the element with the climate) serves as the measure for the optimum performance of each element.

- b) The design of the 'climate-balanced' structure deals with the building in isolation from its surroundings. The external thermal impacts are defined without regard to the effect of the immediate surroundings.

3.3.4 The findings of the study are assembled to establish the planning and design recommendations for community development. This includes three aspects: "housing layout", "shelter design", and "building elements".

The recommendations for the last two aspects (the 'shelter design' and the 'building elements') are drawn on the basis of the design guidelines for the 'climate-balanced' structure, developed earlier in the study through an operation referred to as "heliothermic planning". It is a planning procedure of the thermal behaviour of a building which considers "...the relative importance of the parts as related to the whole" of the building. (ibid, p.126).

The planning recommendations for housing layout are derived from studies which consider the effect of built forms and landscape elements on the micro-climate around, on and within buildings. For example, the effect of building grouping on the wind-flow pattern within the group, and the effect of the wind-flow enveloping a building on the flow inside, are considered (see Fig.6). Also considered is the effect of trees and vegetation in the immediate surroundings of a building /

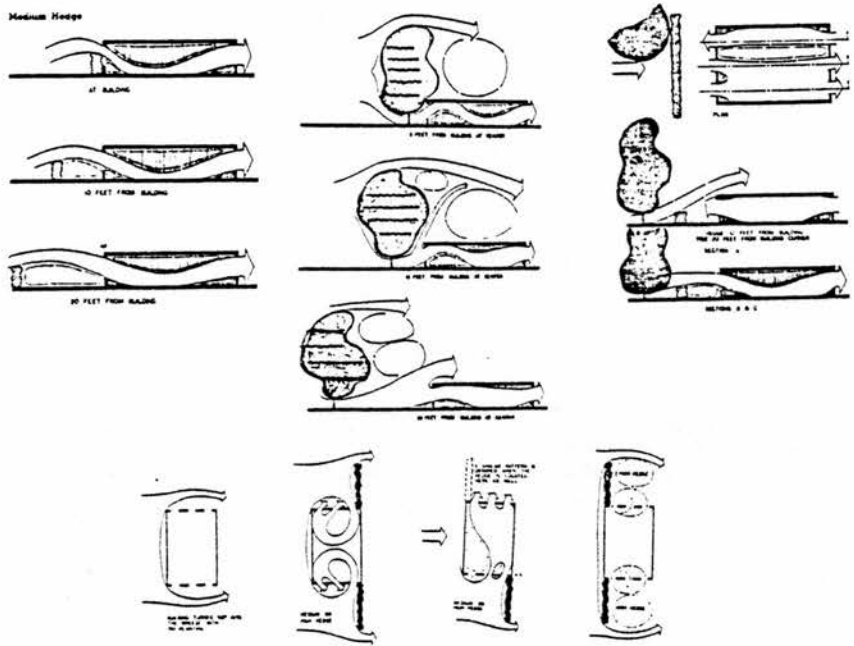


Fig. 7: "Air flow pattern modification with landscaping."  
(from: Olgyay, 1963, p.102)

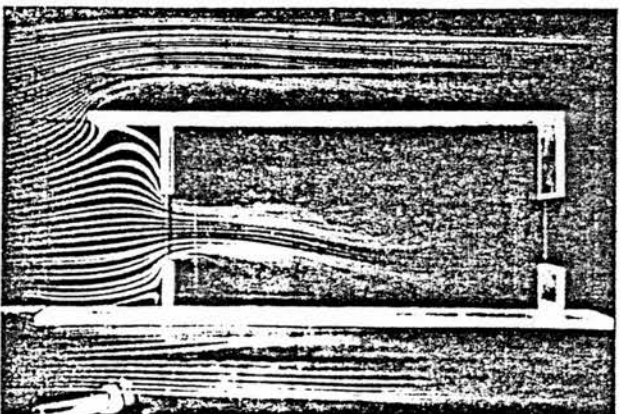
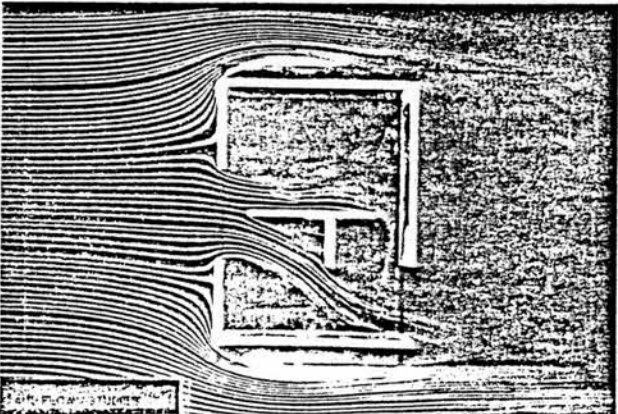
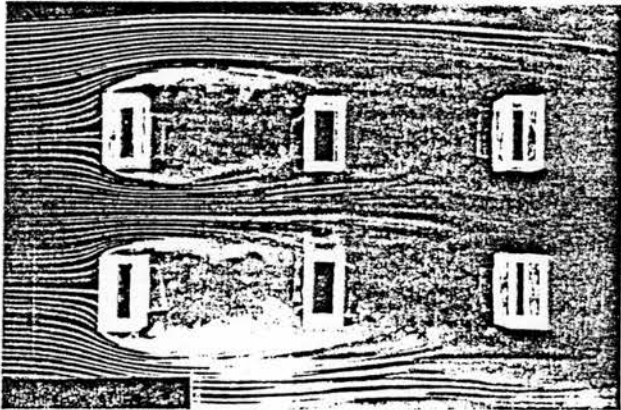
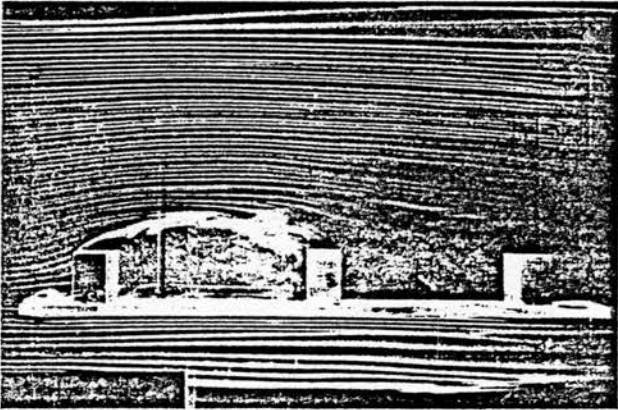


Fig. 6: Examples of Olgyay's analysis of wind flow around and within buildings  
(from: Olgyay, 1963, pp. 101-111)

building on the wind around and within the building (see Fig.7).

The point which needs emphasising is that the study establishes no correlation between the building/microclimate interaction, and the design of the so-called 'climate-balanced' structure. Instead, the study relies on the design of this structure, though unwittingly, on an incomplete description of the interaction, and confines itself to the effect of the building on the internal climate.<sup>1</sup>

#### 4. THE METHOD OF GIVONI

The method which Givoni (1969, 1976 sec. ed.) introduces for the climatic design of buildings, deals mainly with warm climates, where discomfort is largely due to high temperatures and humidities. The method relies on a refined biophysical model of the man/environment thermal system to establish a series of conclusions to be used in planning the thermal behaviour of the building in order to control the indoor climate.

##### 4.1 Techniques of Indoor Climate Control

Givoni introduces the Index of Thermal Stress, I.T.S., (1976, pp.90-99), which combines the metabolic and environmental thermal stresses on the human body and expresses them in /

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1. Chapter 4 deals with the analysis of the principles of the interaction between the building and its environment.

in a single parameter, the sweat rate. The use of this index to evaluate the human requirements of comfort in a given climate, determines as well the choice of the approach to indoor climate control. Two techniques of control are considered (ibid, pp.312-314);

- a) Reliance on an effective ventilation pattern to attain the thermal balance of humans, on the assumption that the construction materials of the building envelope ensure internal surface temperatures below the level causing thermal stress.
- b) Attainment of thermal balance by a reduction in internal air and surface temperatures below the outdoor level, effected by the specific selection of building materials, and the absence of ventilation.

#### 4.2 Design-Aid

The choice between these two techniques, as well as the possibility of having to rely on mechanical means to achieve comfort conditions, depends on the climate at hand, and is facilitated by the use of the "building bioclimatic chart" introduced by Givoni (ibid, pp.314-319). It is a psychrometric chart modified to meet the criteria of thermal stress on the basis of the I.T.S. The range of conditions of the climate under which thermal balance is attainable, by each of the controlling techniques, is shown on the chart overleaf (see Fig.8).



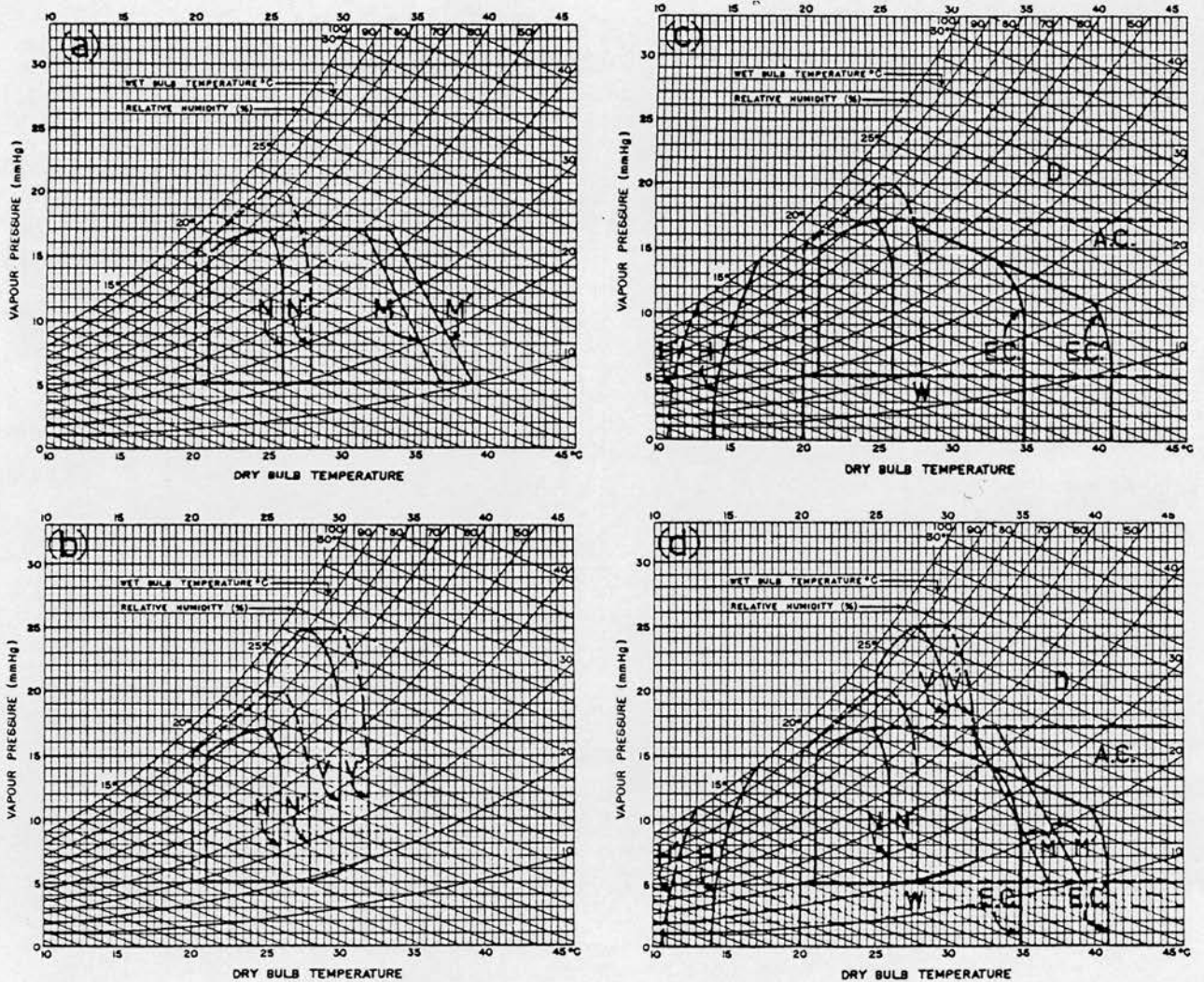


Fig.8: The Building Bioclimatic Chart - showing the neutral 'comfort' zone, N, and the range of conditions under which comfort is attainable by reduction in temperature, M, ventilation, V, evaporable cooling, EC, mechanical means, AC, and humidification, W. H defines the region in which heating is unnecessary. The regions, marked by prime letters, (') define 'permissible' conditions, (from: Givoni, 1976, pp.315-316).

#### 4.3 The Structure of the Method

The design procedure which Givoni proposes is similar, in principle, to that of Olgyay, though not as simple and orderly. Three steps constitute the structure of the procedure (ibid, pp.311-319):

- a) Analysis of the climatic characteristics of the concerned region.
- b) Choice of the approach to indoor climate control, i.e. effective ventilation system or reduction in indoor temperatures, by the use of the building bioclimatic chart.
- c) Identification of the necessary features of building design which ensure comfortable indoor climate according to the chosen technique of control.

The application of this procedure is carried out for three types of warm climates, to illustrate the relevant design principles in each case (ibid, pp.340-372). The climates considered are "hot-dry", "warm-wet" and "Mediterranean"; their characteristics have been adopted from Miller's climatic classification (Miller, 1961).

#### 4.4 General Remarks

The principle of design which Givoni proposes for the climatic types considered in his study, are based on a series of analyses of the interaction between the effects of various design parameters on the internal climate.

For /



For example, the analysis illustrates the effect of the colour of external surface on the performance of both the thermal insulation (ibid, pp.126-132) and the heat capacity of walls (ibid, pp.132-137). The conclusion reached concerning the former, for instance, indicates that "...there is an optimal thermal resistance determined by the external colour and existing ventilation. An increase beyond this optimal level produces little or no improvement on indoor conditions of comfort" (ibid, p.132).

Another example of the interaction between design parameters is the effect of surface orientation on the internal temperatures, which the study argues can be effectively cancelled by particular combinations of other parameters. It is indicated that: "With adequately insulated walls of light external colour, and effectively shaded windows, internal temperature differentiation with orientation may be negligible" (ibid, p.230).

Also, natural ventilation has received particular attention. Givoni argues that in some cases, better conditions of ventilation can be achieved when the wind is oblique (at  $45^{\circ}$ ), rather than perpendicular, to the inlet windows. The pattern of air flow in a room is shown to be influenced by two factors: "The pressure distribution around the building and the inertia of the moving air" (ibid, p.289).

However, there is a serious limitation in Givoni's approach relating to the fact that the studies of the building/environment interaction again deal with the building in isolation /

isolation from its surroundings. For example, in the study of wind-induced natural ventilation and its relation to the pressure distribution around the building, no consideration is given to the effect of building grouping on the wind flow, in general, and on the pressure distribution in particular, despite the fact that Givoni and Pacink (1973) have studied such an effect before. Also, the plan shape of the building, which is a major element in the spatial relationships between a building and its surroundings has received relatively little attention and then totally outside this context. It is indirectly considered in a discussion of the parameters affecting the thermal quality of a building as a whole, which in turn affects the capacity of the mechanical heating system. Givoni's approach, therefore, falls into the same conceptual error as Olgyay's, by giving an incomplete account of the building/environment interaction.

## 5. THE METHOD OF FORWARD ANALYSIS<sup>1</sup>

The 'forward analysis' method evolved from the practical need to incorporate the climatic design of buildings into the overall design process.<sup>2</sup> The aim is to allow climatic decisions /

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1. This method was originally introduced in the United Nations monograph on Climate and House Design, Koenigsberger, Mahoney, and Evans, 1971, and elaborated in Koenigsberger, Ingersoll, Mayhew, and Szokolay, 1974. The term 'forward-analysis' is introduced in the latter.
  2. See Chapter 5, for a detailed discussion on the overall design process.

decisions to be taken "in conjunction with other factors", thus providing the means to achieve consistency of the overall design.

This is done by dividing the decision-making process of climatic design into three stages: "forward analysis", (prior to the 'sketch' design), "plan development", and "element design" (see Fig.9). The method relies on the 'Mahoney tables' to provide a simplified, step-by-step procedure for climatic analysis, and for establishing design principles. (Evans, JM.(1973), who is a co-author in Koenigsberger et al (1971), describes a process for analysing climatic data to arrive at design recommendations. Fig.10 illustrates the structure of this process, and is included for comparison with the structure of the other methods mentioned earlier).

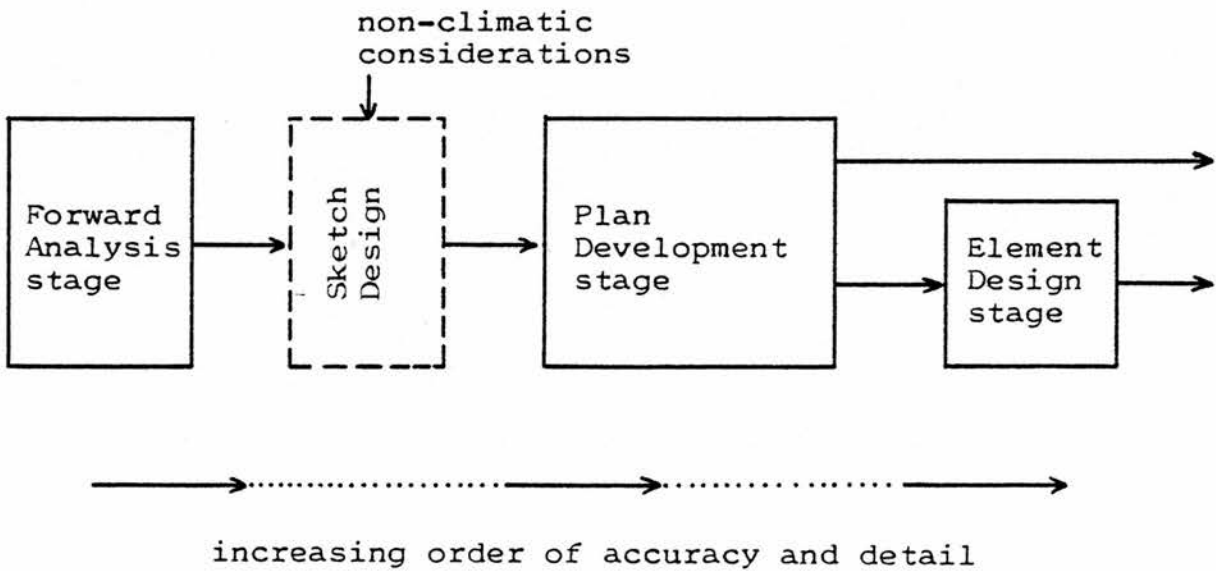


Fig. 9: Schematic presentation of the 'forward analysis' Method



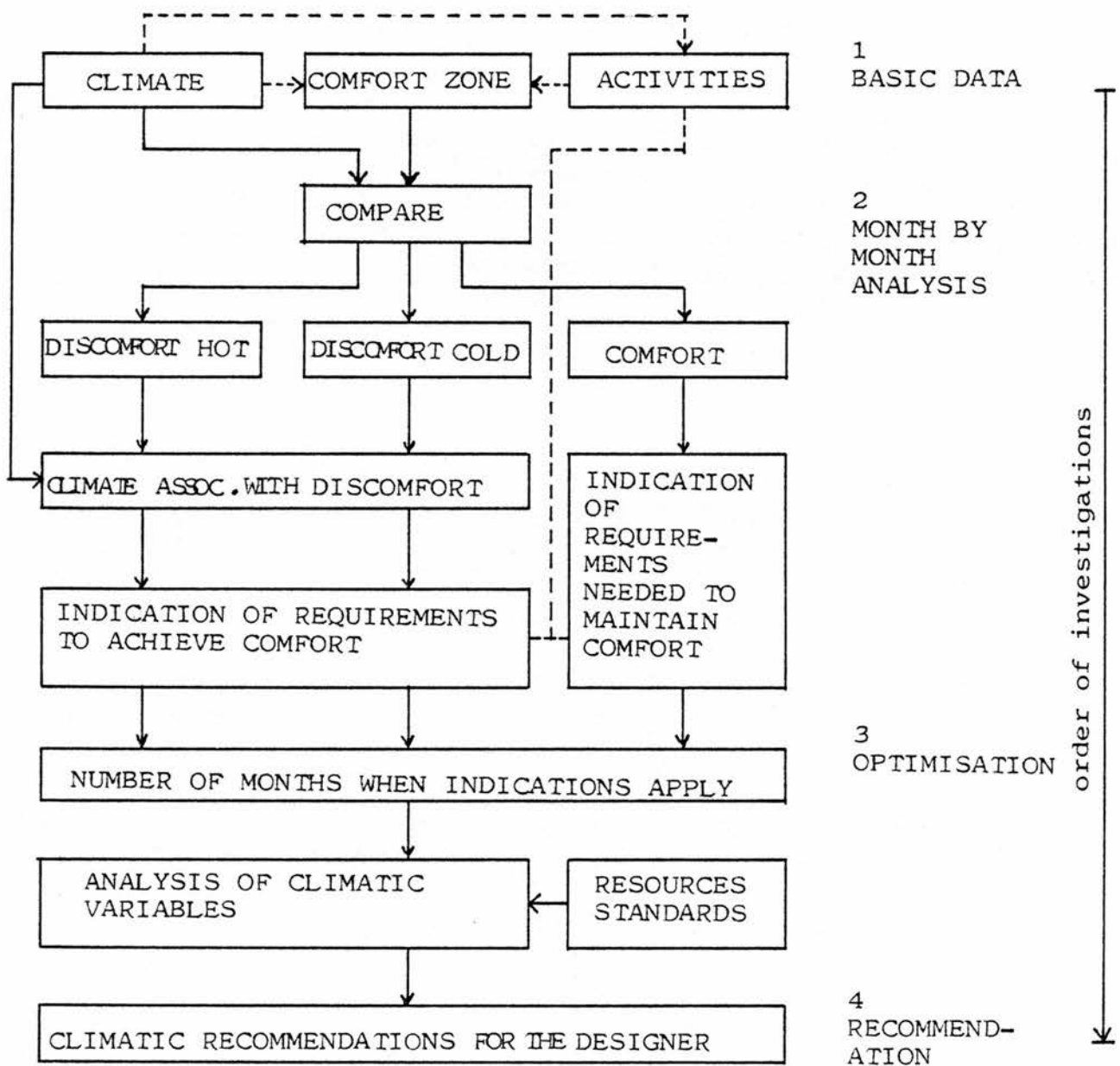


Fig. 10: "The process of analysis to derive climatic design recommendations." (from: Evans, 1973, p. 2)

### 5.1 The Forward Analysis Stage

By "forward analysis", Koenigsberger et al (1974 p.237) mean "analytical work which precedes the formulation of a design solution...", the result of which is presented in the form of "performance specification" so as not to prejudice the design. Certain parameters of the regional climate (air temperature, rain, wind and relative humidity) are chosen and processed using the Mahoney tables, which enable an architect to arrive at the relevant performance specification for the climate at hand, (see Table 2). A method for the regional climate analysis is introduced by Koenigsberger, et al (1974, pp.13-22) for use at this stage.

### 5.2 The Plan Development Stage

For convenience, Koenigsberger et al (1971, pp.43-47) introduce a number of 'plan types' for the architect to choose from on the basis of the performance specifications defined at the previous stage. The chosen plan type is to be refined at the following stage.

At this stage, however, considerations are extended, on social and functional grounds, to include the outdoor spaces around buildings. This important aspect, which distinguishes this method from the other two discussed earlier, is based on a rational approach to climatic design, as the following remarks indicate:

"Climatic design is not restricted to the prevention of uncomfortable conditions; it must include the creation of comfortable conditions, /

Item	recommendation for sketch design	recommendation for element design
Layout	<ul style="list-style-type: none"> <li>- orientation north and south (long axis east-west)</li> <li>- compact courtyard planning</li> </ul>	
Spacing	<ul style="list-style-type: none"> <li>- open spacing for breeze penetration</li> <li>- as (above), but protection from hot &amp; cold wind</li> <li>- compact lay-out of estates</li> </ul>	
Air movement	<ul style="list-style-type: none"> <li>- rooms single banked, permanent provision for air movement</li> <li>- double banked rooms, temporary provision for air movement</li> <li>- no air movement requirement</li> </ul>	
Openings -size	<ul style="list-style-type: none"> <li>- large openings, 40-80%</li> <li>- medium openings, 20-40%</li> <li>- very small openings, 10-20%</li> </ul>	<ul style="list-style-type: none"> <li>- large: 40-80%</li> <li>- medium: 25-40%</li> <li>- small: 15-25%</li> <li>- very small: 10-20%</li> </ul>
-position		<ul style="list-style-type: none"> <li>- in north &amp; south walls at body height on windward side</li> <li>- as above, openings also in internal walls</li> </ul>
-protection		<ul style="list-style-type: none"> <li>- exclude direct sunlight</li> <li>- provide protection from rain</li> </ul>
Walls and Floors	<ul style="list-style-type: none"> <li>- light walls, short time-lag</li> <li>- heavy external &amp; internal walls</li> </ul>	<ul style="list-style-type: none"> <li>- light, low thermal capacity</li> <li>- heavy, over 8 h time-lag</li> </ul>
Roofs	<ul style="list-style-type: none"> <li>- light, insulated roofs</li> <li>- heavy roofs, over 8 h time-lag</li> </ul>	<ul style="list-style-type: none"> <li>- light, reflective surface, cavity</li> <li>- light, well insulated</li> <li>- heavy, over 8 h time-lag</li> </ul>
External feature	<ul style="list-style-type: none"> <li>- space for out-door sleeping</li> <li>- protection from heavy rain</li> </ul>	<ul style="list-style-type: none"> <li>- space for out-door sleeping</li> <li>- adequate rainwater drainage</li> </ul>

Table 2: Performance specifications for sketch design and element design (adapted from: 'Mahoney tables' 3 and 4, Koenigsberger et al, 1974, p. 243 and p. 260).

conditions, and in the tropics [as in any other climate] this includes conditions out of doors. The task of the designer does not end at the four walls of a building. It extends to the space around the building".  
(Koenigsberger et al, 1971, p.47)

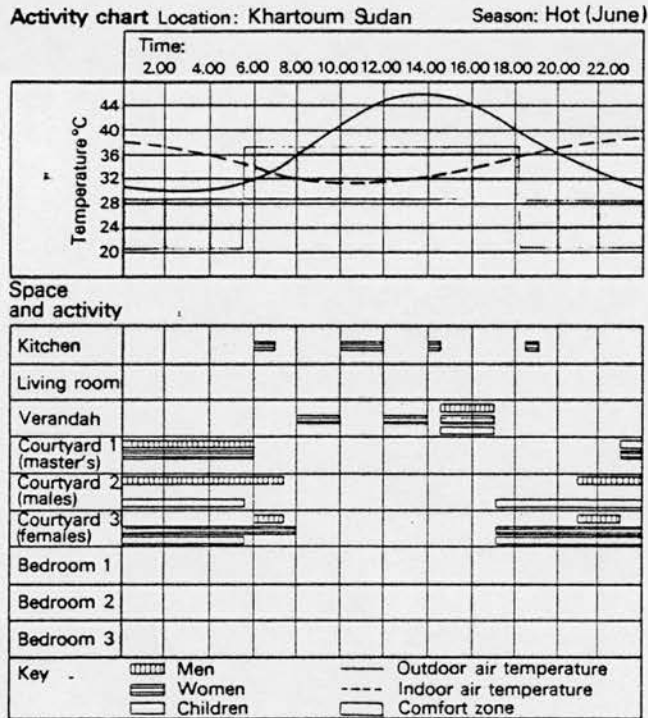


Fig.11: Example of the use of Activity Chart (from: Koenigsberger et al, 1974, p.249)

An activity chart (see Fig.11) is introduced to enable the architect to plan the use pattern of a space (whether external or internal) in correlation with the daily pattern of the changes in its air temperature, so as to coincide with times of comfort conditions. Also, "further refinement" of /



of the specifications of the sketch design are developed, concerning the layout, spacing, and orientation of buildings, as well as the elements of landscape which help to improve the climate of the outdoor space.

### 5.3 The Element Design Stage

At this stage, the climatic analysis is devoted to the detailed considerations of the fabric components of the building. This includes arrangements of openings, design of shading devices and choice of construction materials, etc. (see Table 2).

### 5.4 Comments

There are two aspects which distinguish the method of 'forward analysis' from the other two methods reviewed earlier. First, it incorporates the climatic design into the overall design process of the building. Secondly, it extends the consideration of the design to the outdoor spaces around the building. The limitations of the method, however, lie predominantly in the way in which the latter is accomplished and which is argued here to be inadequate.

The method relies on design recommendations, mostly of general information, as the means to improve the climate of outdoor spaces. At the plan development stage the design evolves from two sources: the performance specifications of the built form, i.e. the outcome of the climatic analysis of the first stage, which includes information about orientation, spacing, etc., and the "design tools for open spaces" /



spaces" (Koenigsberger et al, 1971, pp.47-49). The latter include recommendations for planting, shading, air movement, etc., for different conditions of warm climates.

The architect's task in the design process is analogous to the making of a choice out of a 'catalogue' of recommendations. The process is structured in such a way that it does not allow the architect to either predict or respond, by design alterations, to the resultant microclimate. Furthermore, the recommendations are made, regardless of the context of the 'surroundings'. It is argued later in this thesis (see Chapter 4) that an adequate control of the building's microclimate depends on an adequate prediction of building performance which necessarily includes prediction of the effect of surroundings on the building's microclimate.

## 6. DEFICIENCIES IN THE CONVENTIONAL APPROACH

The basic assumption underlying the climatic design of buildings is that performance prediction during the design stage should enable the architect to compose an acceptable solution, or a range of solutions, for the building on the basis of criteria for satisfactory conditions of the environment. Knowledge of the interaction between the building and its environment is essential for this assumption to materialize.<sup>1</sup>

The /

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1. See Chapter 4.

The three methods which have been analysed rely on an incomplete description of the building/environment interaction in so far as they deal, primarily, with the control of the internal climate. Two of these methods (Olgyay and Givoni) disregard the effect of the building under design on its microclimate; and all three of them do not allow the design to respond to the building's microclimate.

This is evident in a number of ways.

6.01 The analysis of the relationship between the 'optimum' building shape and the building's climatic performance is confined to the effect of the parameters of the shape on the internal climate. The shape/microclimate relationships are not included. For instance, in the design of the 'balanced' structure, Olgyay's criteria for basic forms and plan shapes are based on the expected internal thermal impacts, as a function of surface orientation and thermal properties of construction materials. In Givoni's method, 'shape' is only considered during the analysis of the overall thermal behaviour of a building, in so far as it affects the rate of heat flow.

6.02 The methods adopt a piecemeal approach to the study of building performance. Performance prediction during design has been restricted to the study of the building in isolation from its surroundings.

The analysis of thermal performance, for instance, relies on concepts such as 'sol-air' temperature, or U-value, which /

which describe the climatic behaviour of parts of buildings. The value of these concepts is mainly due to the way in which they make a complex task of performance prediction manageable. In many cases, such concepts have proven useful to the architect and the engineer in designing heating or air-conditioning systems, where gross estimations are acceptable.

A problem arises, however, when these concepts are used to predict the performance of the building piecemeal e.g. disregarding the effect of surroundings. The external thermal impact of a building depends on the 'form' under consideration (as Olgyay demonstrates) as it does on the amount of incoming radiation - the latter is a function of the spatial relationship between the building and its surroundings which is not considered in deciding upon the optimum form. Moreover, a piecemeal approach to the analysis of building/environment interaction during design is bound to give unreliable prediction of, for example, the wind flow characteristics around the building. Such characteristics as pressure distribution and wind speed and direction influence both the thermal performance and the ventilation condition of a building.

It is argued later, in Chapter 4, that the climatic performance of a building is a function of two independent factors: the building's climatic behaviour, and the building's relationship to its surroundings. Restricting the prediction of the performance of a building to knowledge of the behaviour of its form is an over-simplification which undermines performance-based /

performance-based design solutions.

6.03 The considerations which have been given to the climate of the outdoor space in these approaches are in the form of given information. Included are brief explanations as to the kinds of effects which built forms and layouts (including elements of the landscape) have on the outdoor climate, followed by design and planning recommendations. This may explain the reason behind such considerations, but it does not explain how to evaluate such effects or at what stage, so that design alternatives can be thought of.

A close look at the structure of the "activity chart" (Fig.11) indicates that it is a 'checking' tool that does not facilitate design responses. The chart is introduced for use in evaluating outdoor as well as indoor spaces. The use of the chart can indicate whether or not the space is expected to be comfortable during the proposed period of use. However, relying on 'air temperature' as a measure of the use pattern/comfort condition relationship of outdoor spaces is limiting, as far as designing is concerned, since it is difficult to establish a correlation between air temperature and the design parameters of the space. A more sensible choice would be wind speed or solar radiation distribution which are sensitive to changes of the geometry of the space, and enough to generate design responses. In this context, the chart in its present form may explain why, but not how, the space is (or is not) comfortable,

6.04 Finally, the strategies which have been adopted in the three methods in relation to the "potential of climatic controls" (Koenigsberger et al, 1974, p.92) (see Fig.12) give no explicit reference to the design of buildings as a potential form of microclimatic control. The strategies include aspects of microclimatology which relate to the 'site climate'. The process of "site selection" (Olgyay, 1963, pp.44-52) gives the architect the chance to avoid unfavourable conditions, i.e. it provides a negative form of control. Similarly, the problems of the urban climate, when considered (Koenigsberger et al, 1974, pp.31-37) could enable acquisition of data representative of the site climate. Both aspects are considered by these methods to be 'microclimate control'.

However /

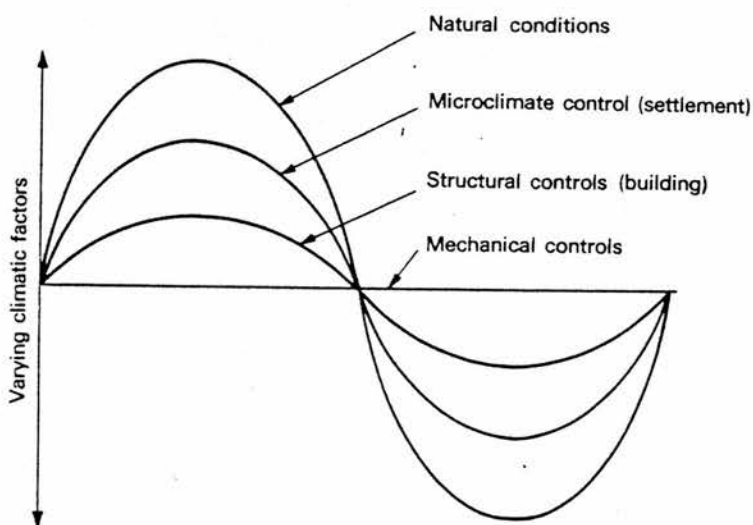


Fig. 12: "Potential of climatic control"  
(from: Koenigsberger et al, 1974  
p.92).

However, the site climate, as indicated in the preceding chapter (Chapter 1) is a fundamentally different concept from that of the building's microclimate. The latter depends on the design of the building, and its control is a function of the building's design. Such articulation of function is not considered in the three major studies which have been analysed, and is necessary in view of the 'linear' structure of their design processes discussed in the following section.

## 7. THE CONVENTIONAL CLIMATIC DESIGN PROCESS

In this section, we analyse the framework of the conventional approach. We begin by identifying the underlying structure of the climatic design process shared by the methods which have been analysed. The analysis of this structure shows the limitations of the conventional approach and suggest the structural reform which is required in order to overcome these limitations.

### 7.1 The Framework

The notion of climatic design, as shared by these three methods, recognises that if one can identify the range of a particular set of climatic parameters, whose combined effect is required for a human to be in a thermally-balanced state, then one should be able to evaluate a given climate leading to discomfort and define the necessary corrective measures. Such measures could then serve as "yardsticks" in /

in planning the physical behaviour of a building at the design stage.

The climatic analyses which are necessary to transform these corrective measures into design guidelines vary from one method to another, as a matter of tactics. For practical reasons, this process is simplified and aided by 'design tools'. The 'Mahoney tables', the 'building bioclimatic chart', and the 'bioclimatic chart', are different forms of design tools. In some cases, such as the 'bioclimatic chart', the design tool is supplemented by design-related activities i.e. the "calculative methods". In others, such as the 'Mahoney tables', it leads directly to performance specifications.

In each case, however, the design tool (and its supplementary activities, if any) constitutes a sub-system within the overall system of the method (see Fig.13).

## 7.2 The Structure of the Conventional Climatic Design Process

From Fig.13, one can see that the structural components, and their inter-relationships in the system of each method, are similar.

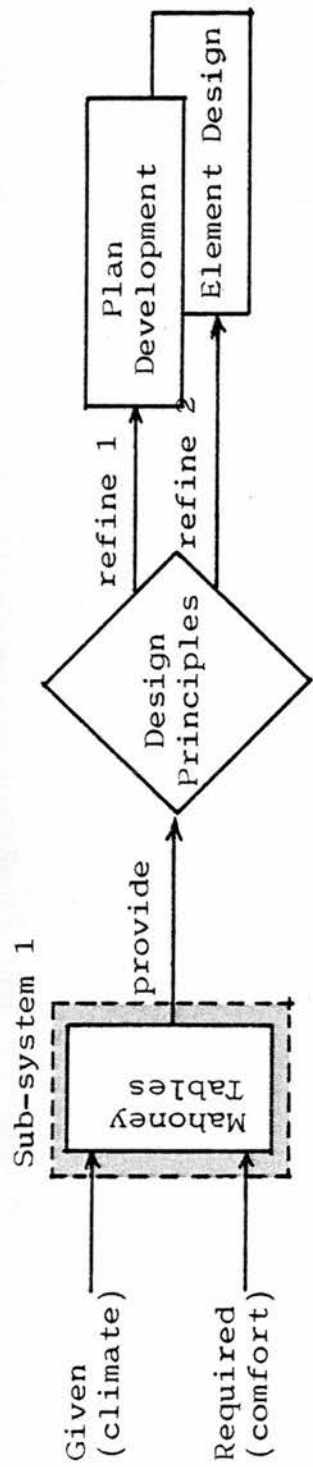
In each case, there is an information input into a sub-system, whereby the processing of the information leads to the provision of principles for the climatic adaptation of buildings.

The input is information about the 'climate' and the 'comfort' /



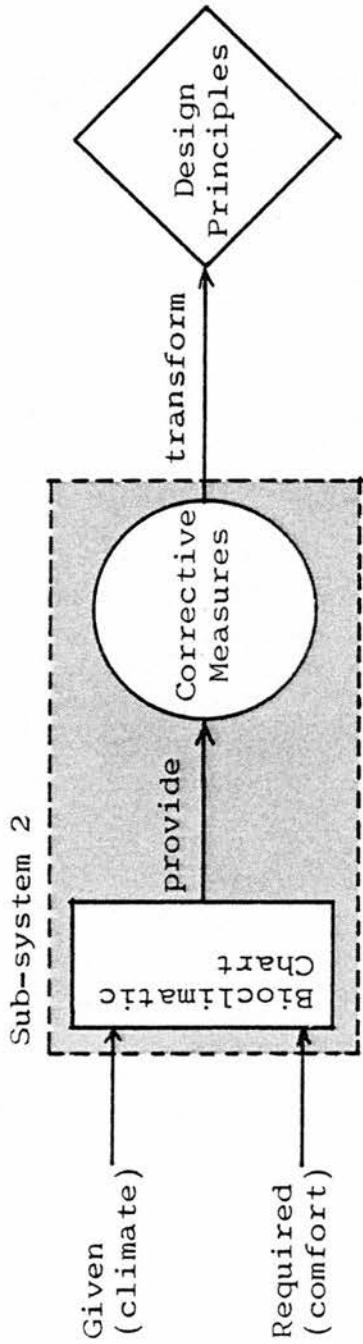
SYSTEM 1:  
The method of  
forward analysis

simple

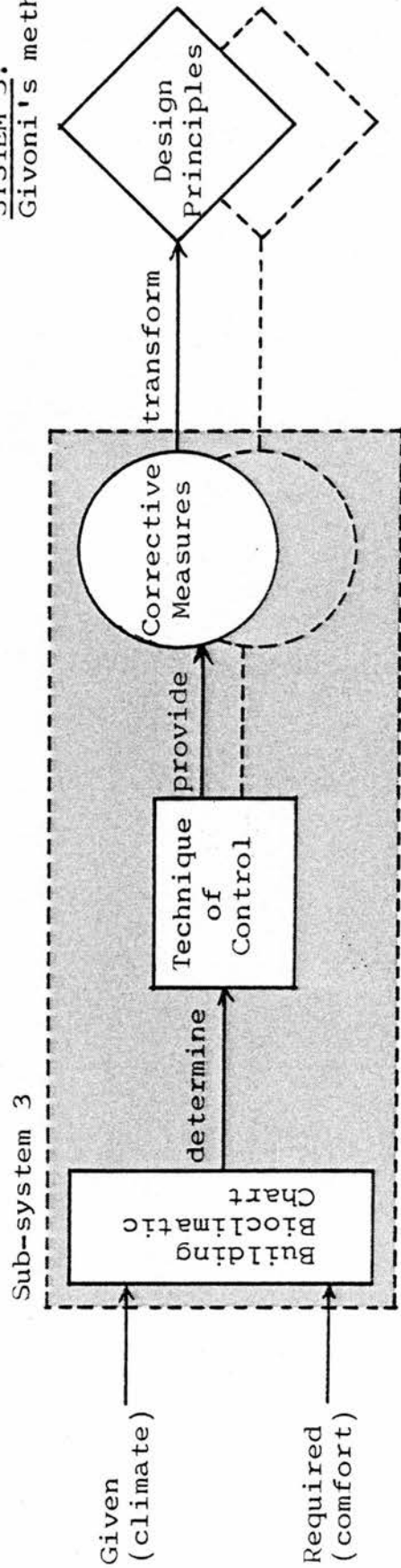


simplicity scale

SYSTEM 2 :  
Olgyay's method



SYSTEM 3:  
Givoni's method



complex

Fig. 13:  
Structural presentation  
of the conventional climatic  
design procedures



'comfort' limits, i.e. the given and the required climatic condition. The structure of the sub-system is part of a particular methodology, planned to fulfill the objective of the method concerned - e.g. emphasising regional variation of architectural expressions in diverse climatic types, seeking precision in predicting indoor conditions, or incorporating the climatic design into the overall architectural design process. The nature of the concluding design principles are bound to reflect the objective which was adopted in each case. This may result in different emphases being assigned to different design parameters.

Despite these differences, the structure of the climatic design process underlying each method is basically the same. To analyse this structure, it is helpful to describe it in terms of the relationship it establishes between the three basic elements involved: Human, H, Climate, C, and Building, B (see Fig. 14).

If /

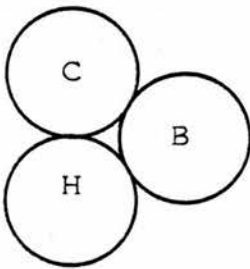


Fig. 14: The structural elements of climatic design - Human, H, Climate, C, and Building, B.

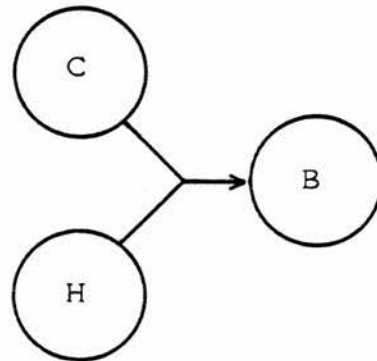


Fig. 15: The structural 'route' of the conventional approach.

If we relate Fig. 13 to Fig. 14, we can see that the conventional approach to climatic design leads to a solution of the building on the basis of knowledge of the 'climate' and human requirements of comfort (see Fig. 15). The structure of the underlying climatic design process (see Fig. 16) comprises three stages:

A descriptive stage in which data on the climate (regional or urban) and human comfort conditions are collected.

An evaluation and diagnosis stage which is a procedure within a sub-system, defined and followed, step-by-step, to enable the designer to evaluate the climate and identify the necessary corrective measures.

A development and synthesis stage in which values of the relevant design parameters are defined and synthesised to compose a solution for the building.

#### 8. A SUGGESTED STRUCTURAL REFORMATION

According to Jones' (1981) classification of the strategies of different design methods, the structure of the 'conventional' climatic design process (Fig. 16) is a "linear" structure embodying "...a sequence of actions. Each action is dependent upon the output of the last but... independent of the output of the later stages" (ibid, p.76).

If the effect of the building on its microclimate is to be controlled, the assessment of this effect must be part of the decision-making process of the building's design. In other /

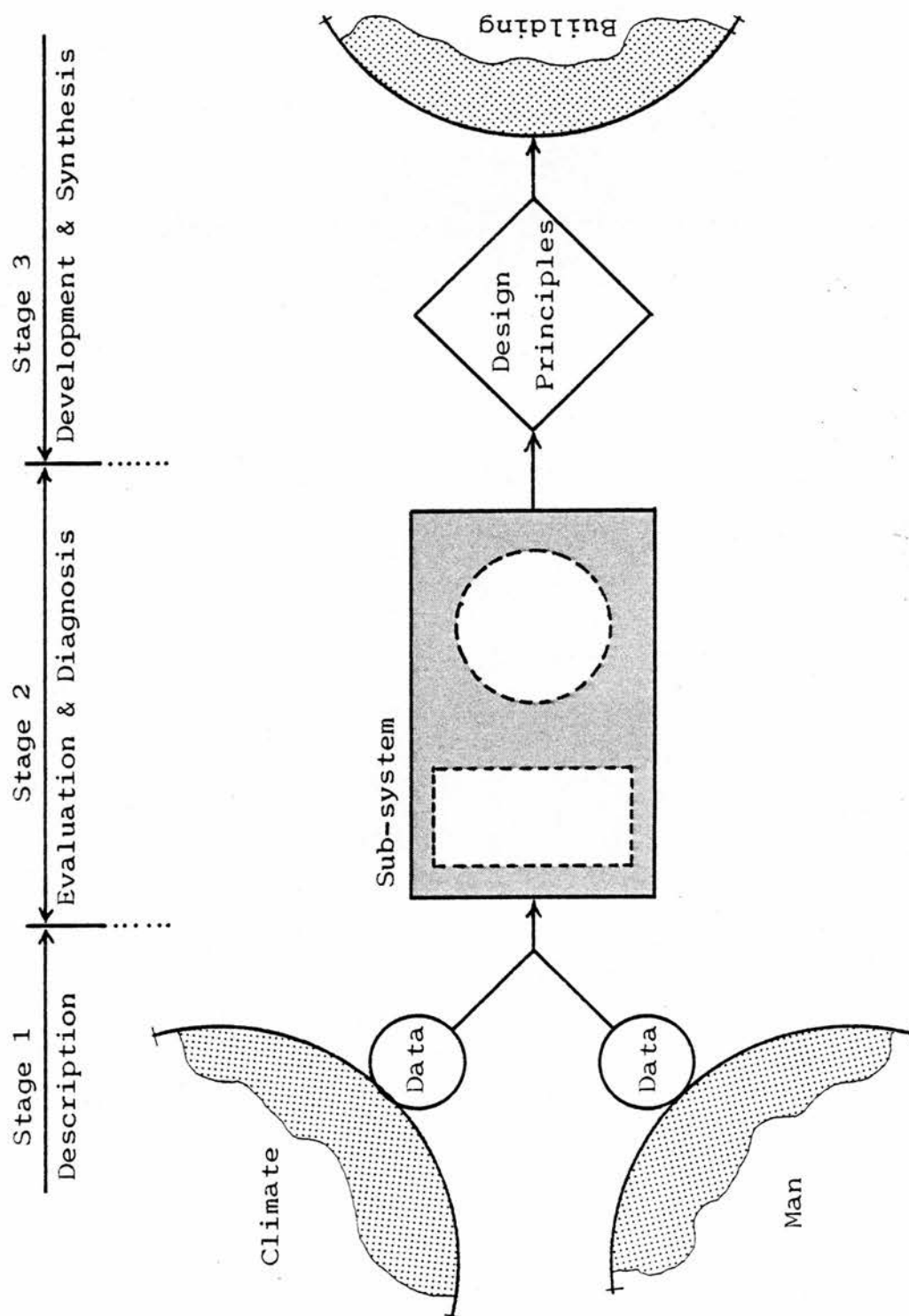


Fig. 16: The structure of the climatic-design process

other words, prediction and evaluation of the climatic performance of buildings with respect to the microclimate need to be incorporated into the climatic design process.

This can be achieved by introducing a structural change into the structure of the conventional climatic design process (see Fig.17). This reformation is a 'feedback' mechanism, linking the 'Building' and the 'Climate', and transforms the process into an 'interactive' one. This 'feedback', and the structure of the would-be 'interactive' climatic design process are developed later in Chapter 5, after a careful analysis of the building/environment interaction (Chapter 4). The aim of the analysis would be to explore the role of the building's microclimate in setting up a comprehensive approach to design.

The /

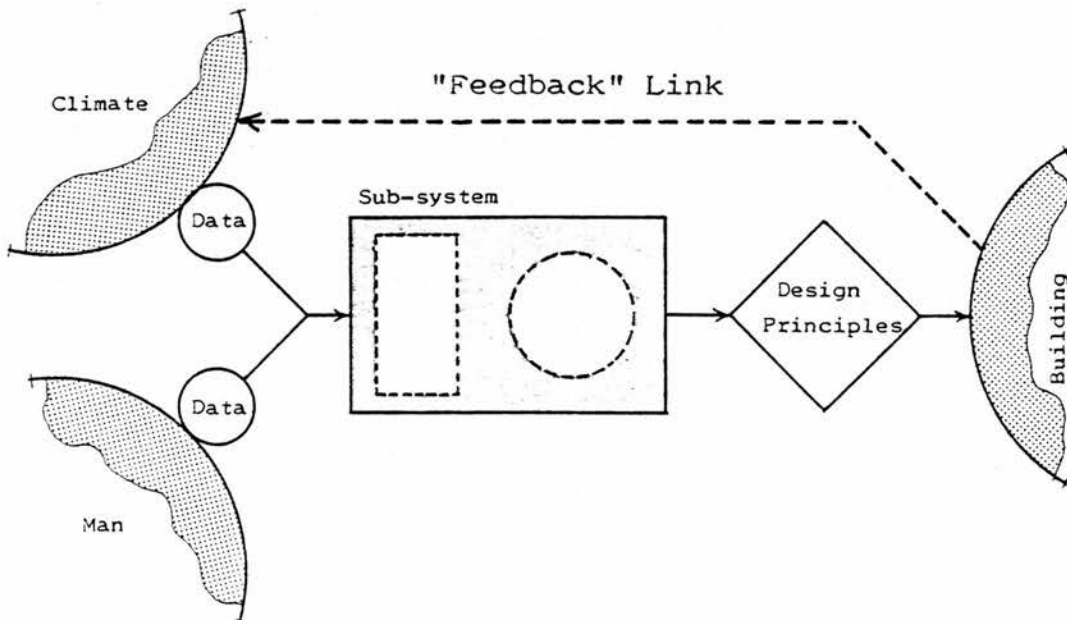


Fig. 17: The missing feedback link

The motivation of this reformation is the development of a structure for a design process in which, at the early stages of design, an initial idea or design concept could be evaluated against the climate condition, to predict the microclimate. Thus, the final design of the building can be based on knowledge of the microclimate it would give rise to.

## 9. SUMMARY AND CONCLUSIONS

This chapter has given an analytical review of the conventional approach to the climatic design of buildings, presented through three best known methods.

The method of Olgyay (1963) evolves from the concept of architectural regionalism. It describes a design procedure for a "climate-balanced" structure and applies it to the design of buildings in diverse climatic conditions to emphasize regional variations. The procedure incorporates the use of a "bioclimatic chart" and a number of calculational methods to establish design principles for the climatic adaptation of the balanced structure in each case.

The method introduced by Givoni (1969, 1976 sec.ed.) seeks precision in predicting the indoor climate of a building. It employs a "building bioclimatic chart" to determine the appropriate technique for the control of the indoor climate, and on which to base the principles of building design.

The /

The "forward-analysis" method (Koenigsberger et al, 1971; Koenigsberger et al, 1974) breaks down the decision-making process of climatic design into stages in relation to the overall design process. It relies on the "Mahoney tables" for the climatic analysis and the establishment of design recommendations.

Reviewing these methods critically exposes the following conclusions:

1. The methods follow a piecemeal approach to the analysis of the building's climatic performance.
2. The proposed design procedures are developed on the basis of a linear structure.
3. The structure is not responsive to the need to control the building's microclimate as a function of design.
4. A more comprehensive approach to climatic design requires a structural reform in the conventional climatic design process, in order to incorporate the building's microclimate in the design of the building itself.

CHAPTER IIIMOTIVATIONS FOR AN  
INTERACTIVE APPROACH  
TO CLIMATIC DESIGNCONTENTS:

1. INTRODUCTION
2. THE CLIMATOLOGICAL SHEATH
3. THE CONCEPT OF CLIMATIC MODIFICATION
4. COMPLEX APPROACHES TO THE RELATIONSHIP  
BETWEEN BUILDING PERFORMANCE AND MICROCLIMATE
5. NOTES ON THE RELATIONSHIP BETWEEN BUILT FORMS  
AND THEIR MICROCLIMATES FROM THE POINT OF VIEW  
OF DESIGN
6. SUMMARY AND CONCLUSIONS



## 1. INTRODUCTION

The framework of the conventional approach to climatic design which was discussed in the preceding chapter operates in the general context of the effect of the 'climate' on building design. There is no doubt that the works connected with this approach have succeeded in emphasising the principle of the regional adaptation of buildings which benefited the climatic design as an aspect proven to be no less important than, for example, the social or behavioural aspects of building design.

However, a serious limitation remains in this approach, which relates primarily to the effect of built forms on their microclimate, i.e. the antithesis of the effect of climate on building design. In the last decade or so, the study of the microclimate around buildings has attracted a great deal of research interest (e.g. Penwarden and Wise, 1975; Hassan, 1974; Ryd, 1970, 1973; O'Sullivan, 1970; O'Sullivan and Greenwood, 1973; Soliman, 1976; Smith and Wilson, 1977). In this chapter we review a number of concepts in this area, all of which point to the need for a comprehensive approach to climatic design which will enable both the building's microclimate and the internal climate to be controlled by means of the design.

## 2. THE CLIMATOLOGICAL SHEATH

The problem of obtaining reliable climatic data is  
as /

as old as Climatology itself. However, for purposes of application in building design, the problem takes on a new dimension. Recent attempts have been made to establish the kind of meteorological information required in solving building problems (e.g. Lacy, 1972). Ryd (1970, 1973) argues that the problem of climatic information lies essentially in the lack of knowledge of the interaction between buildings and their environments. The regional data of macroclimates provide insufficient information about the real stress facing buildings. Ryd's remarks (1970, p.29) are:

"...it cannot be taken for granted that the different climatological parameters exert stresses on a building in the way one might have supposed from the values obtained in large-scale recordings of weather conditions..."

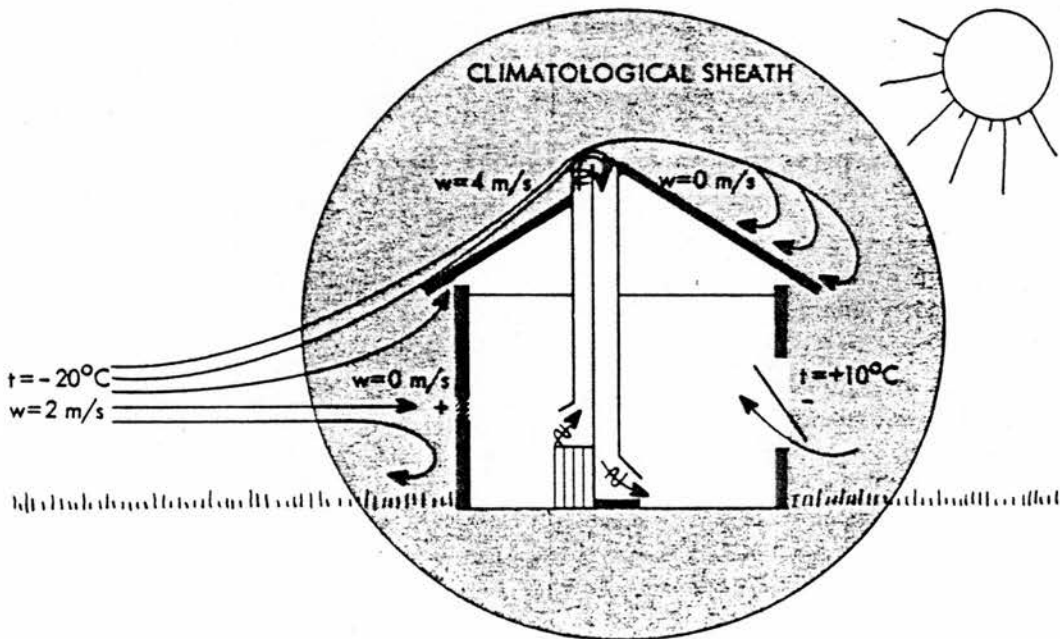


Fig.1: The Climatological Sheath  
(from: Ryd, 1970, p.29)

In a simple analysis of the building/environment interaction, Ryd discusses the nature of the climatic modifications in the immediate vicinity of a building caused by the building itself. The most significant of these are the changes in the wind velocity and direction around and above the building, the local differences in temperature influenced by the shading pattern of the building, and the local pressure distribution caused by local variables of wind and temperature. This microclimate enveloping the building is described by Ryd as the "climatological sheath" (see Fig.1).

Ryd regards this sheath as "that part of the prevailing climate which exerts the real stresses on a house [ or any building]" (1970, p.30). She also links it to the design of the building:

"The difference between the stresses of the climatological sheath from outside and the qualities desired for the indoor climate provides the limit conditions for the climatological performance of the house" (ibid).

This distinguishes Ryd's approach to climatic design from the conventional approach discussed earlier (in Chapter 2). What the above quotation implies is that a reliable prediction (and manipulation) of building performance, during the design stage, would necessarily include knowledge of the "climatological sheath". In his introductory speech at the opening of the CIB Colloquium "Teaching The Teachers On Building Climatology", Wallen (1973, p.10) emphasised this argument by pointing to the relationship between the indoor climate and the building's climatic /

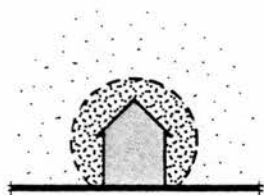
climatic sheath:

"It is only with information about the micro-climate of the building sheath, and the physical processes involved in the transport of moisture and heat through material, that the future indoor climate of a building can be adequately predicted... So far most predictions about indoor climates of a future building have been based on macro-climatological data obtained far away from the building".

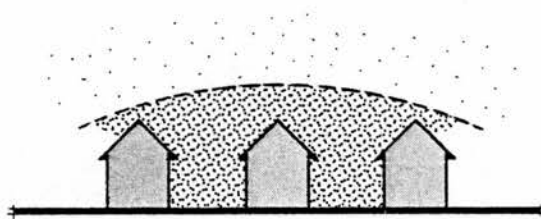
A point should be made at this stage, regarding the difference between the building's microclimate (discussed in Chapter 1) and the "climatological sheath". The latter expresses the principles of building/environment interaction by referring, exclusively, to the climatic modifications introduced by the building per se. In principle, the performance of the building could be assessed on the basis of knowledge of the site climate and prediction of the climatological sheath, since the former includes, by definition, the influence of surroundings.

The building's microclimate refers to the climate of outdoor spaces in the immediate vicinity of the building, including that part which envelops the building (i.e. the climatological sheath). This microclimate is the result of the cumulative effects of the building and its immediate surroundings.

There is a practical reason for the comprehensiveness of the building's microclimate, which relates to the design process, or more precisely, to performance prediction during the design process. Practically, it would not be possible, to /



The Climatological Sheath



The building's microclimate

to study the climatological sheath additively, i.e. to study the modifications which the building introduces into the site climate. Prediction of wind flow around buildings, for example, requires the study of the building and its neighbouring buildings as a single built form<sup>1</sup>.

### 3. THE CONCEPT OF CLIMATIC MODIFICATION

In his concern with the climate inside buildings and its link with the microclimate around buildings, O'Sullivan (1970) introduced "the concept of climatic modification". This concept recognises the building as "a climatic modifier" (Hardy and O'Sullivan, 1967) which acts as a filter between man /

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1. See Chapter 4 for a detailed discussion of the structure of the prediction process of building performance during the design stage.

man and his environment. Such a filter is explained as having three "sections":

- "(a) The conversion of the meteorological climate of the region, to the correct microclimate around the building.
  - (b) The modification of this microclimate by the properties of the building envelope itself, i.e., by the properties of the materials in construction.
  - (c) ... The building is expected to be designed so that the third is only 'fine tuning' of the environment so produced, by the thermal plant, the lighting etc."
- (O'Sullivan and Greenwood, 1973, p.2).

The "Newcastle experiments" (O'Sullivan, 1970) provide data on the effect of built forms on the urban climate. The phenomena which have been observed relate to "heat islands" in the urban climate, demonstrating the cumulative effects of built forms on air temperature. The modifications caused by each individual building are the 'sub-phenomena' of the heat-island phenomenon, and are well recognised in the concept of climatic modification (mentioned above in "section" (a) ). O'Sullivan's argument (ibid, p.13) is that knowledge of the microclimate around buildings provides "a tool...which, in the first instance, could be used to demonstrate the implications of design decisions in quantitative terms and ultimately to predict their effects [primarily, during the design stage]". His conclusions indicate that:

"Theoretical consideration of the factors affecting microclimate around buildings has often been thought too complex for use in design guides. This study suggests, however, that some of these factors, explained in terms of a simple concept, can be used to advantage in siting and designing buildings" (ibid, pp.21-22).

The /



The concept of climatic modification emphasises the economic benefits that result from the correct application of climatic design principles. By making full use of the potential for climatic modification inherent in built forms, which necessarily includes control of the building's microclimate, the reliance on energy-based systems of environmental controls is reduced to 'fine tuning'.

#### 4. COMPLEX APPROACHES TO THE RELATIONSHIP BETWEEN BUILDING PERFORMANCE AND MICROCLIMATE

Some of the existing concepts for predicting building performance, during design, such as the 'U-value' and 'force-coefficient' concepts, embody in their structures assumptions about variables of the building's microclimate.

4.0.1 The thermal transmittance coefficient, or U-value, is a measure of the ability of a building element such as a roof or wall to conduct heat out of the building (BRE, 1975). It depends on the thermal properties of the element, and is influenced by the moisture content, the wind speed near the element's surface, and internal conditions. This coefficient is defined as (ibid, p.2):

$$U = 1/(R_{si} + R_{so} + R_{cav} + R_1 + R_2 \dots)$$

where,  $R_{si}$  = internal surface resistance

$R_{so}$  = external surface resistance

$R_{cav}$  = resistance of any cavity within the building element

$R_1, R_2 \dots$  = resistance of slabs of material

The /



The external surface resistance  $R_{so}$  comprises two coefficients, involving radiative and convective heat exchanges. The radiation coefficient is mainly dependent on the surface emissivity; the convection coefficient depends primarily on the wind speed near the surface, and is taken as (Markus and Morris, 1980, p.273):

$$h_{co} = 5.8 + 4.1V \quad (W \ m^{-2} K^{-1})$$

where  $h_{co}$  = external convection coefficient  
 $V$  = external wind speed  $(ms^{-1})$

Surface	Exposure	Wind speed (m s <sup>-1</sup> )	$h_{co}$ (W m <sup>-2</sup> K <sup>-1</sup> )	$R_{so} = 1/(Eh_r + h_{co})$ (m <sup>2</sup> K W <sup>-1</sup> )
Roof	Sheltered	1.0	9.9	0.07
	Normal	3.0	18.1	0.045
	Severe	9.0	42.7	0.02
Walls	Sheltered	0.7	8.7	0.08
	Normal	2.0	14.0	0.055
	Severe	6.0	30.4	0.03

Table 1: Values for  $R_{so}$   
 (from Markus and Morris, 1980,p.273)

Markus and Morris (1980) give the values of  $R_{so}$  (see Table 1), for walls and roofs, used in current British practice. They have been established on the basis of values of wind speeds, empirically derived to represent three 'standard' /

'standard' conditions of exposure - namely, "sheltered", "normal", and "severe". Of course, the wind speed around buildings is much more varied than those categories suggest, and is influenced by design parameters relating to building shape and the spatial relationship between the building and its surroundings.

4.0.2 The assessment of wind loads on buildings takes into account the effect of the building's shape on the wind flow enveloping it. This flow is determined by two sets of variables: the wind variables of the site climate (before the building exists), and the parameters describing the shape of the building. Eaton (1975, p.1) explains that:

"...the building itself interacts with the wind, modifying the flow pattern in its own neighbourhood and generating a new flow regime over its own surface which contributes further small-scale turbulence to the flow. It is this turbulent flow over the surfaces of a building which determines the wind loads on the building..."

The British Code of Practice on Wind loads (BRE, 1978) provides a procedure for calculating wind loads on buildings;

Step 1: To determine the design wind speed,  $V_s$  (i.e. the site climate) by converting the basic wind speed of the region,  $V$ , on the basis of knowledge of surroundings<sup>1</sup>:

$$V_s /$$

---

1. The basic wind speed,  $V$ , is the maximum speed of a certain gust size (normally 3 sec.), recorded over a certain period of time (50 years).

$$V_s = V S_1 S_2 S_3$$

- where
- $S_1$  = topography factor (see Table 2)
  - $S_2$  = factor for ground roughness, building size, and height above ground (see Table 3)
  - $S_3$  = a statistical factor for the expected life-span of the building.

The design wind speed is converted to dynamic pressure,  $q$ , using the relationship:

$$q = K V_s^2,$$

where  $K$  is a constant ( $0.613 \text{ ms}^{-1}$ )

Step 2: To calculate, on the basis of information of the building's shape, the wind force,  $F$ , using the relationship:

$$F = C_f q A_e$$

- where
- $C$  = force coefficient
  - $A_e$  = effective frontal area of building.

Table 4 shows the force coefficients for different plan shapes of rectangular buildings.

4.0.3 As far as the building/microclimate relationship is concerned, these two concepts are used in the context of a problem-solving approach; their use allows particular variables of the building's microclimate to be considered during design, but not controlled as a function of design.

For/

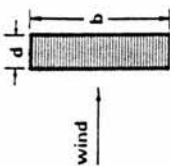
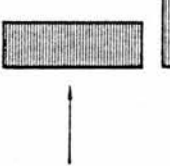
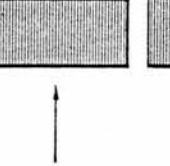
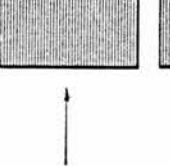
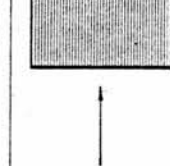
Topography	Value of $S_1$
All cases, except as below	1.0
Very exposed hill slopes and crests where acceleration of the wind is known to occur	1.1
Valleys shaped to produce a funnelling of the wind	
Sites that are known to be abnormally windy due to some local influence	
Steep sided, enclosed valleys, sheltered from all winds	0.9

Table 2 (above): Values for  $S_1$

Table 3 (right): Values for  $S_2$

(from: BRE, 1978, p.4)

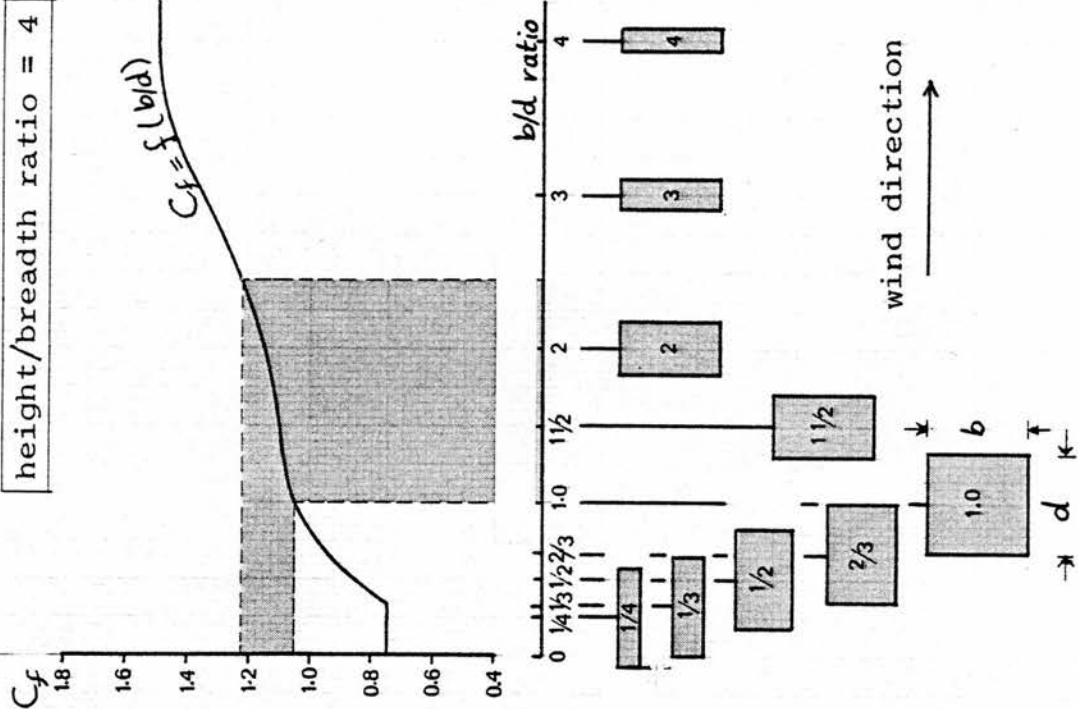
Surface category	1. Open country with no shelter			2. Open country with scattered windbreaks			3. Country with many windbreaks; small towns, outskirts of large cities			4. Surface with large and numerous obstructions eg city centres		
	3-sec gust	5-sec gust	15-sec gust	3-sec gust	5-sec gust	15-sec gust	3-sec gust	5-sec gust	15-sec gust	3-sec gust	5-sec gust	15-sec gust
Height above ground level metres												
3 or less	0.83	0.78	0.73	0.72	0.67	0.63	0.64	0.60	0.55	0.56	0.52	0.47
5	0.88	0.83	0.78	0.79	0.74	0.70	0.70	0.65	0.60	0.60	0.55	0.50
10	1.00	0.95	0.90	0.93	0.88	0.83	0.78	0.74	0.69	0.67	0.62	0.58
15	1.03	0.99	0.94	1.00	0.95	0.91	0.88	0.83	0.78	0.74	0.69	0.64
20	1.06	1.01	0.96	1.03	0.98	0.94	0.95	0.90	0.85	0.79	0.75	0.70
30	1.09	1.05	1.00	1.07	1.03	0.98	1.01	0.97	0.92	0.90	0.85	0.79
40	1.12	1.08	1.03	1.10	1.06	1.01	1.05	1.01	0.96	0.97	0.93	0.89
50	1.14	1.10	1.06	1.12	1.08	1.04	1.08	1.04	1.00	1.02	0.98	0.94
60	1.15	1.12	1.08	1.14	1.10	1.06	1.10	1.06	1.02	1.05	1.02	0.98
80	1.18	1.15	1.11	1.17	1.13	1.09	1.13	1.10	1.06	1.10	1.07	1.03
100	1.20	1.17	1.13	1.19	1.16	1.12	1.16	1.12	1.09	1.13	1.10	1.07
120	1.22	1.19	1.15	1.21	1.18	1.14	1.18	1.15	1.11	1.15	1.13	1.10
140	1.24	1.20	1.17	1.22	1.19	1.16	1.20	1.17	1.13	1.17	1.15	1.12
160	1.25	1.22	1.19	1.24	1.21	1.18	1.21	1.18	1.15	1.19	1.17	1.14
180	1.26	1.23	1.20	1.25	1.22	1.19	1.23	1.20	1.17	1.20	1.19	1.16
200	1.27	1.24	1.21	1.26	1.24	1.21	1.24	1.21	1.18	1.22	1.21	1.18

Plan shape	$\frac{L}{W}$	$\frac{b}{d}$	Cf for height/breadth ratio:					
			$\frac{1}{2}$	1	2	4	6	
	$\geq 4$	$\geq 4$	1.2	1.3	1.4	1.5	1.6	
	$\geq 4$	$\leq \frac{1}{4}$	0.7	0.7	0.75	0.75	0.75	
	3	3	1.1	1.2	1.25	1.35	1.4	
	3	$\frac{1}{3}$	0.7	0.75	0.75	0.75	0.8	
	2	2	1.0	1.05	1.1	1.15	1.2	
	2	$\frac{1}{2}$	0.75	0.75	0.8	0.85	0.9	
	$1\frac{1}{2}$	$1\frac{1}{2}$	0.95	1.0	1.05	1.1	1.15	
	$1\frac{1}{2}$	$\frac{2}{3}$	0.8	0.85	0.9	0.95	1.0	
	1	1	0.9	0.95	1.0	1.05	1.1	

b breadth of building across wind direction  
d depth of building in direction of wind

Table 4:  
Force coefficient,  
C . for rectangular  
buildings.  
(from: BRE, 1978,  
p. 10)

Fig. 2: The relationship between force  
coefficient and plan shape for  
a fixed height/breadth ratio.



For example, standard U-values are normally included in building regulations, in terms of 'performance specifications'; the architect is required to design a wall or roof with thermal performance characteristics matching that of a specified U-value, under assumed micro-climatic conditions of wind-exposure. Similarly, the force coefficient (though a function of the building's shape) is used to calculate wind loads on a given built form with known parameters of shape i.e. the force coefficient is pre-determined.

In the case of wind load calculation, an interactive approach which permits control of the micro-wind is possible, at least in principle, though this may not be the case in practice. On the basis of knowledge of the relationship between the building's shape and force coefficient (see Table 4), there is a unique force coefficient for every plan shape (with known height/breadth ratio) considered. This means that, for an acceptable range of force coefficient there will be a corresponding range of acceptable plan shapes (see Fig.2). Therefore, when pre-set limits for wind loads are given (i.e. known design wind speed, direction, and acceptable force coefficients) one can decide upon the acceptable plan shape before calculating the wind loads on the building.

This hypothetical approach to wind load calculations is similar to the approach considered by Page (1973). In his concern with a constructive use of climatic data in building /

building design, Page (ibid, p.97) speaks of the "safe location" and "safe form" by pointing to the need "...to consider the building and the wind as an interactive system. Hence by the choice of built form [one] can choose the wind load".

Although the aim of including the control of the microclimate may not be part of the existing approach for dealing with structural problems in building design, it certainly must be part of any comprehensive approach for the climatic design of buildings that aims to include other environmental problems such as those concerned with wind and sun conditions in the outdoor spaces around buildings. Two mutually related principles are emphasized by the approach outlined above, and are of particular relevance to the climatic design of buildings:

- a) The microclimate around a building is dependent on the design of that building.
- b) The design of the built form is no longer a mere solution to a given climatic problem, but rather a measure involved in shaping the problem in the first place.

##### 5. NOTES ON THE RELATIONSHIP BETWEEN BUILT FORMS AND THEIR MICROCLIMATES FROM THE POINT OF VIEW OF DESIGN

In order to control the building's microclimate by the design of the building we need knowledge of the effect of the design parameters on the variables of the microclimate. The choice of variables and parameters can be made in view of /



of the ability to control the microclimate, and the function for which it is controlled.

The functional significance of the building's microclimate was mentioned earlier (in Chapter 1), where it was noted that the microclimate affects people in the outdoor spaces around buildings as well as the environmental performance of the buildings themselves. The relationship between these aspects and the variables of the microclimate is discussed later, in Chapter 5, where a set of parameters of the built form is distinguished.

The ability to control the building's microclimate depends on how sensitive the climatic variables are to changes in the parameters of the built form, and to what extent the effect of the form is predictable by means of currently available predictive techniques. In this context, some variables of the building's microclimate may be distinguished as more controllable than others.

For example, the analysis of urban climates shows that air temperature depends, among other things, on the material properties of the built forms. How much of the change in urban temperatures can be attributed to the properties of built forms is difficult to quantify. On the other hand, solar radiation distribution and wind flow in open spaces around buildings depend exclusively on the geometry of buildings. The shading pattern, for example, directly expresses the form/micro-sun interaction, and can be used during /

during the design process as a measure of the ability of the building to modify the micro-sun. Furthermore, the use of 'heliodon' or computer-based techniques (Smith and Wilson, 1976) during design enables prediction and manipulation of the building's microclimate to be made.

As far as the design of buildings is concerned, it is reasonable to assume that the wind and the sun are the two most readily controllable variables of the building's microclimate. In the last decade or so there has been a considerable amount of research, of diverse nature, dealing with the interaction between built forms and these two aspects.

For example, Penwarden and Wise (1975) studied the wind flow around two buildings of different heights, in order to identify the effect of the geometry of the buildings on the flow at the pedestrian height around the group (see Figs. 3 and 4). The study is accompanied by a number of case studies in which unpleasant conditions for pedestrians have been observed.

Others were equally concerned with internal conditions of comfort as a function of the microclimate around buildings. Muktadir (1975) for example, investigated the relationship between natural ventilation and the grouping of buildings in warm-humid climates; he studied the wind velocity at the 'inlet' window as a function of the spatial relationship of a group of buildings with uniform heights.

Kenworthy /

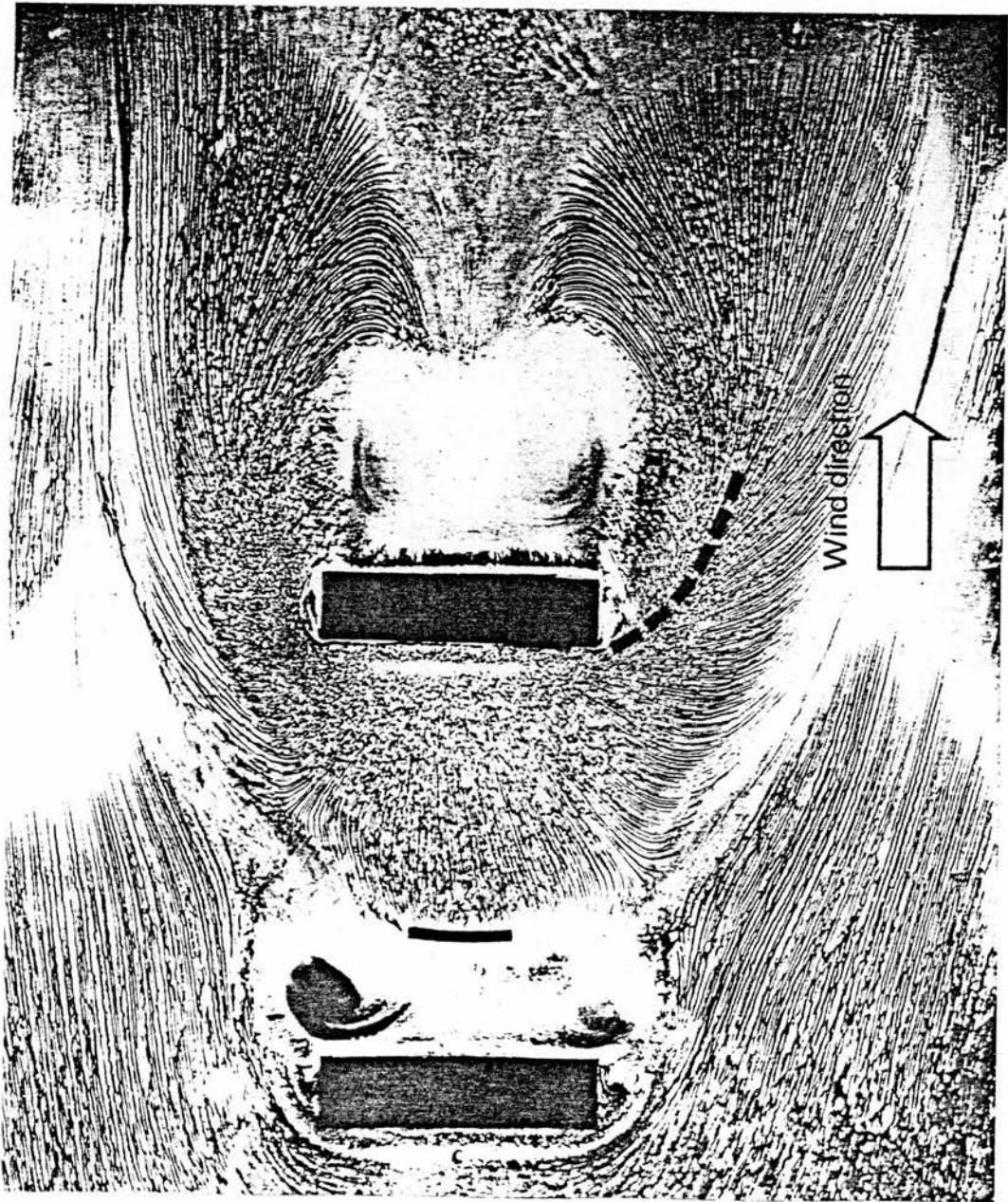
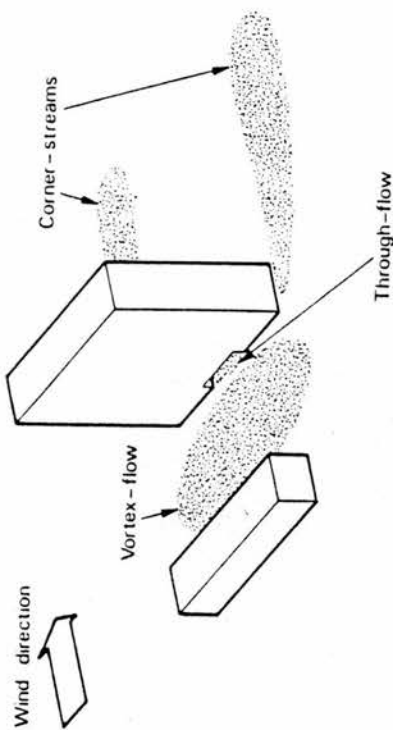


Fig. 3: Example of the pattern of flow at ground level around a tall building, with a low building at a distance to windward.

----- approximate positions of maximum speed.

(from: Penwarden and Wise, 1975, p.2)



Region	$R_H$	$R$
Vortex	0.5	1.3
Corner	0.95	2.5
Through	1.2	3.0

Fig. 4: Regions of increased wind speed at pedestrian level, with some typical speed ratios.

$R_H = \frac{\text{wind speed at pedestrian height}}{\text{free wind speed at the top of the tall building of height } H}$

$R = \frac{\text{wind speed at pedestrian height}}{\text{free wind speed at pedestrian height on open site}}$

(from: Penwarden and Wise, 1975, p.4)



Kenworthy (1978, 1980) relied on statistical analysis of "fuel consumption returns" for a number of individual dwellings in a particular high rise block (22 storey, with known surroundings) to demonstrate the effect of the differences in the micro-climatic exposure on the indoor climates. The analysis, coupled with wind tunnel tests of the airflow around the block during the period chosen for investigation, showed that the consumption pattern reflects micro-climatic differences, particularly those of the wind velocity gradient, and that such differences "are brought about both by changes in the [local] climate and by the building form itself" (1980, p.242).

The /

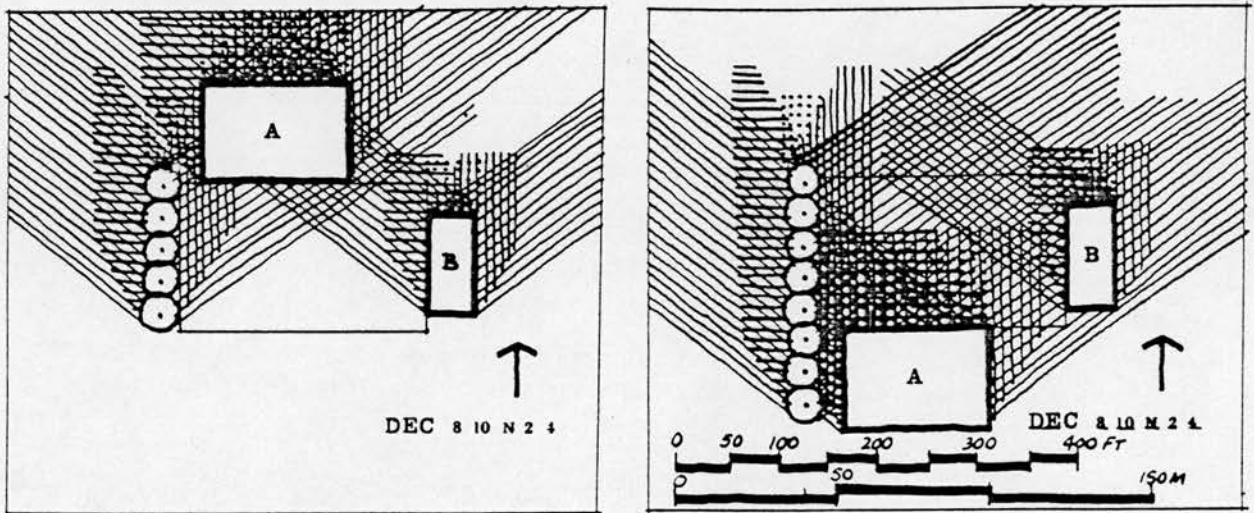


Fig. 5: With building (A) moved North, even in December, a considerable portion of the open space is in full sun all day.  
(from: Laurie, 1976, p.172)

The microclimate around buildings has also attracted a great deal of interest with regard to landscape architecture. Laurie (1976) discussed the microclimate as "a determinant of form"; he studied, among other things, the shading pattern of a combination of buildings and trees, (see Fig.5) to demonstrate ways in which the "microclimate can be specifically created by design, and how the use of open spaces may be affected by it" (ibid, p.167).

Later in Chapter 7 we review some of the research in the area of built form/microclimate interaction, with a view to showing the ways in which knowledge of this interaction can best be implemented in the decision-making process of design.

## 6. SUMMARY AND CONCLUSIONS

The effect of built forms on their microclimates has attracted, and is continuing to attract, research interest in the climatic design of buildings. The literature offers sufficient material to initiate the development of an interactive approach to climatic design. The particular material reviewed in this chapter has led to the identification of two principles, which are fundamental to this approach.

The first of these is that the microclimate in which the building exists and functions is dependent on the design of the building itself. The second recognises the possibility to exert a deliberate influence, by means of the design of the built form on the microclimate so as to reduce the climatic stresses /

stresses on the building and provide advantageous microclimatic conditions for people out-of-doors.

A structuring of the climatic design process so as to embody these two principles is necessary in view of the deficiency of the conventional climatic design process in dealing with microclimatic control. The development of an interactive approach to climatic design is the subject of Part II of this thesis.

PART II

THE DEVELOPMENT OF AN INTERACTIVE  
APPROACH TO CLIMATIC AND MICRO-  
CLIMATIC DESIGN

CONTENTS:

Chapter IV	A Design-Orientated Analysis of the Interaction between Buildings and their Environments
Chapter V	Development of an Interactive Climatic Design Process
Chapter VI	Examples of Interactive Design in Traditional Architecture and of Partial approaches in Contemporary Architecture



## INTRODUCTION TO PART II

Having analysed, in the first part of this thesis, the conventional approach to the climatic design of buildings, and indicated its shortcomings, it is necessary to establish the principles of an adequate approach to design and develop the structure of the design process which places it in practice. This is the aim in Part II, which contains three chapters.

The first of these (Chapter 4) is a design-orientated analysis of the interaction between buildings and their environments. In it we analyse the climatic behaviour of buildings to illustrate the structure of building/environment interaction. We then proceed to develop the framework within which to explore the principles of the prediction process of building performance during the design stage of a building.

The second chapter (Chapter 5) deals with the development of an interactive climatic design process on the basis of embedding the structure of building/environment interaction in the overall design process of a building. We do this by first, developing a conceptual framework of the interactive design process on the basis of knowledge of the climatic behaviour of buildings. We then proceed to introduce logical arguments relating to the description of building/environment interaction, with the aim of simplifying the complex task of performance prediction, thus rendering it manageable during the design process. The framework is then refined, /

refined, and elaborated into an interactive climatic design process.

The third chapter (Chapter 6) contains particular examples of traditional built forms and settlements structures, and a few examples of contemporary design solutions. We analyse the examples of traditional architecture to illustrate the approach underlying their forms, and show its similarity to the interactive climatic design approach developed in this thesis. We also analyse the examples of contemporary architecture to illustrate the interest they show in controlling the microclimate of the built environment. By comparing these two approaches (the traditional and the contemporary) we emphasize the comprehensiveness of the interactive approach of this thesis (and of building traditions) in dealing with the planning and design of the built environment.

CHAPTER IVA DESIGN-ORIENTATED ANALYSIS OF  
THE INTERACTION BETWEEN BUILDINGS  
AND THEIR ENVIRONMENTSCONTENTS

1. INTRODUCTION
2. THE STRUCTURE OF THE INTERACTION BETWEEN BUILDINGS AND THEIR ENVIRONMENTS
  - 2.1 Structural Relationships
  - 2.2 The Model
3. DEVELOPMENT OF A DESIGN-ORIENTATED MODEL OF BUILDING/ENVIRONMENT INTERACTIONS
  - 3.1 Structural Distinction
  - 3.2 Design Requirements of B
  - 3.3 Building/Environment Model of Interaction from the point of view of DESIGN
4. THE BUILDING/ENVIRONMENT SYSTEM OF INTERACTION
  - 4.1 The Phenomenon of Multiple Modification
  - 4.2 Building/Environment System of Interaction
    - 4.2.1 The System
5. THE 'ENHANCEMENT' OF THE BUILDING'S CLIMATIC MODIFICATIONS
6. SUMMARY AND CONCLUSIONS

## 1. INTRODUCTION

Knowledge of the climatic behaviour of buildings i.e. how they interact with their environments, is the basis of performance prediction during the design stage of a building. It is also the basis for establishing criteria of adequate performance.

Reliance on incomplete description, or partial control of the building/environment interaction is bound to undermine any performance-based design solution. This is the case with the conventional approach to the climatic design of buildings. An analysis of this approach (in Chapter 2) indicated that it lacks the capacity for allowing the design of the building to respond to the building's microclimate. It also ignores a whole range of design-related micro-climatic problems, such as the effect of neighbouring buildings on the thermal performance of the building under consideration.

A more comprehensive approach would necessarily take into consideration the effect of the building on its microclimate, and the effect of this on the design of the building.

In this Chapter, an attempt is made to analyse the principles underlying the interaction between the building and its environment, with the aim of clarifying the role of the microclimate in the setting up of an adequate approach to design.

We/

We start by reviewing a theory of building/environment interaction introduced by Wilson (1973) and elaborated by Lord and Wilson (1980). The theory is in the form of a formal model embodying structural relationships between man, building, and environment. The analysis of this model allows some inner relationships within the structure of the interaction to be made explicit. A design-orientated model of the interaction is then introduced, using this elaboration, and embodying the conceptual treatment of the building's microclimate as inherent in the design of the building.

Since the building interacts with its surroundings via its microclimate, the prediction of building performance during the design stage would necessarily include the effect of the surroundings on the building's microclimate. This is discussed here in the context of what we may call 'the phenomenon of multiple-modification', which has led us to introduce the principle of enhanced climatic modification as a prime consideration in the climatic design of buildings.

## 2. THE STRUCTURE OF THE INTERACTION BETWEEN BUILDINGS AND THEIR ENVIRONMENTS

By expressing the relationship between people and buildings through the physical fields of the environment in which they both are immersed, Lord and Wilson (1980) construct a theory of building/environment interaction. This is a formal structural model of physical relationships which underlies /

underlies the principles of the interaction. We shall examine the structure of building/environment interaction using this model.

## 2.1 Structural Relationships

The theory structures the change in the environment of an empty site which results from placing a building on the site, and formally exposes the requirements which the design should satisfy.

An empty site can be described in terms of the environmental fields (radiation, air temperature, wind, etc.) which constitute the physical environment of the site. Placing a building on the site, immersed in these fields, changes their values. The building is said to operate on the initial environment,  $E_0$ , of the site to produce a new environment  $E_1$ , both inside and around the building,  $B$ . This is formally expressed as:

$$B(E_0) = E_1 \quad (1)$$

The description of the initial environment can be made on the basis of data of the regional or local (urban) climate, or the site climate as conditioned by the immediate surroundings.<sup>1</sup>

Lord /

---

1. These climatic concepts were discussed in Chapter 1 of this study. In the case that  $E_0$  is the site climate practical difficulty may arise and requires further elaboration, see Sec. 4.2 of this Chapter.

Lord and Wilson specify two requirements for a satisfactory performance of the building:

- a) An environmental-function requirement: the new environment  $E_1$  should be satisfactory for human occupation in terms of their activity and well-being. The effect of  $E_1$  on a human,  $H$ , is expressed as:

$$E_1(H) = H_+ \quad (2)$$

where  $H_+$  is a human satisfied with his environment.

- b) A stability requirement: the building must not be affected by the stresses imposed by the new environment. This requirement is expressed as:

$$E_1(B) = B \quad (3)$$

## 2.2 The Model

The three relations given above determine the structure of the building/environment interaction:

$$B(E_0) = E_1 \quad (1)$$

$$E_1(H) = H_+ \quad (2)$$

$$E_1(B) = B \quad (3)$$

The analogue in this model of the architect's task is to find a  $B$  which will satisfy these requirements, for the given  $E_0$ . The physical laws which govern the interaction, the /



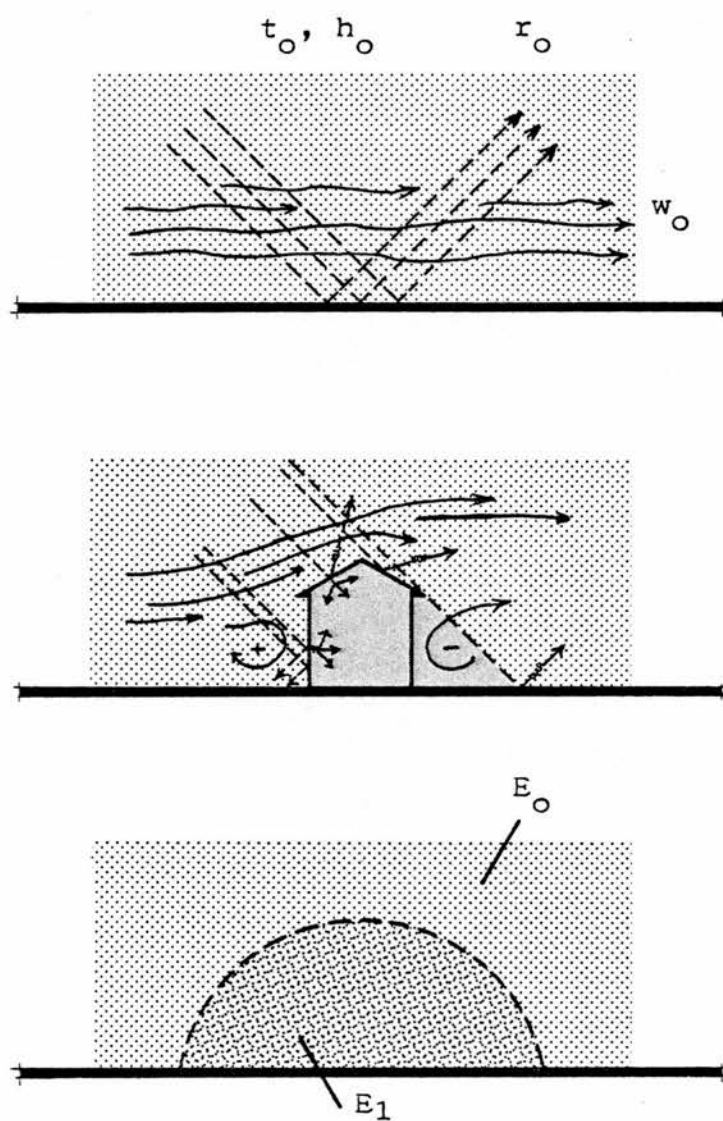


Fig. 1: The effect of the building on the environmental fields

the assumptions which we make about  $H_+$  (e.g. human comfort conditions) and the approximation involved in the description of  $E_0$  influence the nature of the solution for B. Equally important is the prediction of  $E_1$ , in space and time, which facilitates design manipulation.

The change of  $E_0$  into  $E_1$  marks the act of the building in time, i.e. before and after B. Wilson (1973, p.413) explains this "temporal arrangement" by indicating that:

"The output of architecture activity is built form. Although a consequence of building may be human satisfaction or pleasure, it is a prediction of that satisfaction, not the satisfaction itself, which influences the form. The form has to exist before the satisfaction..."

To predict  $E_1$  is to study the action of the building in space. Such action has two characteristics; it takes place outside and inside the building's envelope, and its capacity is spatially limited, especially outside the envelope. Moving away from the building we reach a point in space at which the effect of the building on the environment is negligible. Thus, we assume that the changes in the environmental fields or the new environment  $E_1$  is confined to a spatial region (see Fig. 1) beyond which the presence of the building has a negligible impact on the initial environment  $E_0$ .

### 3. DEVELOPMENT OF A DESIGN-ORIENTATED MODEL OF BUILDING/ENVIRONMENT INTERACTION

$E_1$ , the result of the physical interaction between the building and its environment, refers inclusively to the new environment both around and inside the building.

The comprehensiveness of  $E_1$  encompasses, as Wilson (1973, p.415) indicates, the "familiar formulation of the building's performance as a mediator between the external and the internal environment of the building". It also encompasses, however, the less familiar, and often overlooked formulation (at least as far as the conventional approach is concerned) which relates to the building's modification of the external environment. This latter consideration dictates the structural distinction which follows.

#### 3.1 Structural Distinction

In describing  $E_1$  we may separate the new environment into two parts. We may refer to that part of  $E_1$  outside, enveloping B (i.e. the building's microclimate) as  $E_{1o}$ . The internal climate is referred to as  $E_{1i}$ . This distinction means that:

$$E_{1o} + E_{1i} = E_1 \quad (4)$$

Then /

Then, we can re-write (1) as follows:

$$B(E_o) = E_{1o} + E_{1i} \quad (1.1)^1$$

In view of the spatial and temporal aspects of the building's action upon its environment, we may elaborate (1.1) by writing:

$$B(E_o) = E_{1o} \quad (1.2)$$

$$B(E_{1o}) = E_{1i} \quad (1.3)$$

This means that the building, B, operates on the initial environment,  $E_o$  to produce its own microclimate,  $E_{1o}$ , and operates on this microclimate to produce its internal climate,  $E_{1i}$ . This distinction is explicit in indicating that the building mediates between its micro-climate and the internal climate, and not between the 'climate' and the internal climate as most of the literature appears to assume. Although a knowledge of  $E_o$  is necessary to predict  $E_{1o}$ , it is  $E_{1o}$ , and not  $E_o$ , which interacts with the building.

The /

- 
1. The numbering system, which is used to identify the structural relations developed in this thesis, refers always to one of the basic relations identified by whole numbers. In this case, (1.1) is relation number one, developed on the basis of (1).

The purpose of this work is to clarify the role of the microclimate  $E_{10}$  in the setting up of an adequate approach to design. The importance of a knowledge of  $E_{10}$  lies not only in the fact that adequate conditions external to a building should be an aim of building design, but also, that internal conditions ( $E_{1i}$ ) are a result of the interaction of a building with its own microclimate  $E_{10}$  (see (1.3) above). This latter aspect is overlooked in many conventional approaches to the prediction of building performance. It is therefore necessary to emphasize the interdependence of the design and the microclimate in any rational adaptation of buildings to their environments.

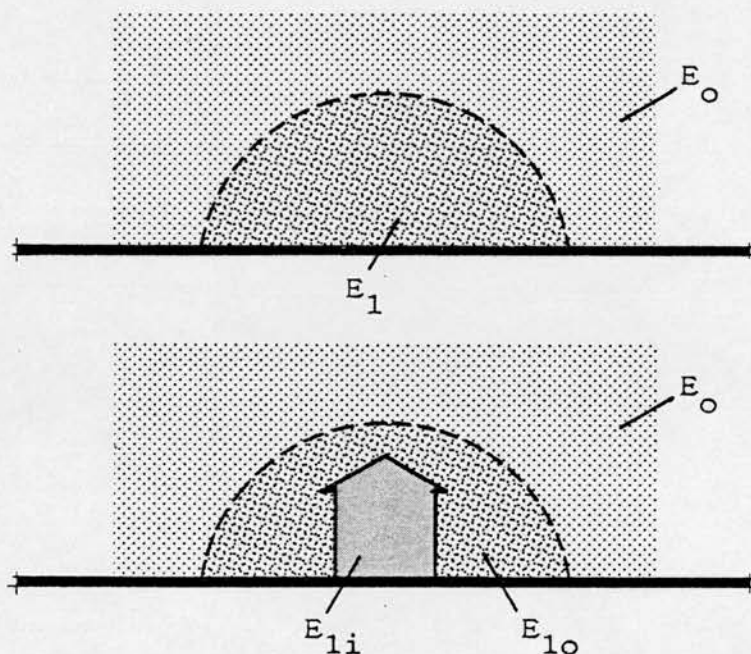


Fig. 2: The building produces its own microclimate  $E_{10}$  and the internal climate  $E_{1i}$ .

### 3.2 Design Requirements of B

a) Having identified the two parts of  $E_1$ , it is now possible to amplify the environmental function of buildings, /



buildings, (2), by indicating that both the building's microclimate  $E_{10}$  and the internal climate  $E_{1i}$  should satisfy human physiological requirements. There are behavioural and psychological factors, such as the association between activity and thermal sensation, to suggest that a 'satisfactory' internal climate for H is different from a 'satisfactory' external climate. We shall not attempt at this stage to identify the characteristics of 'satisfactory' conditions; we shall simply indicate the distinction between satisfactory indoor and outdoor conditions by writing:

$$E_{10}(H) = H_+ \quad (2.1)$$

$$E_{1i}(H) = H_+ \quad (2.2)$$

b) The attempt to impose a similar distinction on the stability requirement, (3), leads to some complexity. While there are some environmental problems (such as the degradation of materials due to solar radiation, or rain penetration) which are totally microclimatic problems, others cannot be attributed to either one of the two parts of  $E_1$ . The interaction between the building and its environment produces a wind force action working against the stability of B. This action is the result of the combined effect of the internal and the external pressures operating on the surfaces of the building's envelope. This means that  $E_1$  as a whole is required not to cause damage to B, and no attempt is therefore made to distinguish between  $E_{10}$  and  $E_{1i}$  /

$E_{1i}$  when considering the design requirement for the structural stability of the building. That is, (3) will remain as it stands in our elaboration of the model.

### 3.3 Building/Environment Model of Interaction from the point of view of DESIGN

We now have a set of relations which describe the structure of a design-orientated model of building/environment interaction:

$$B(E_o) = E_{1o} \quad (1.2)$$

$$B(E_{1o}) = E_{1i} \quad (1.3)$$

$$E_{1o}(H) = H_+ \quad (2.1)$$

$$E_{1i}(H) = H_+ \quad (2.2)$$

$$E_1(B) = B \quad (3)$$

(1.2) indicates that the building produces its own microclimate; (1.3) indicates that the building mediates between its microclimate and its internal climate; (2.1) and (2.2) describe the functional requirements of the building's microclimate and the internal climate; and (3) describes the stability requirement of the building's interaction with the environment it produces.

This version of the building/environment model of interaction has been formulated so as to emphasize the role of the building's microclimate. This has been done for the following reasons:

- a) The microclimate determines the success or failure of /



of the outdoor spaces as locations for various activities.

- b) The microclimate is the true environment in which the building exists and to which it responds in producing the internal climate.
- c) The model enables the role of the microclimate in the design process to be investigated.

In this way, we acquire adequate insight into the task of the architect. In order to control fully the interaction between the building and its environment, the architect must ensure two things: that the solution for B will produce a satisfactory microclimate, and that a satisfactory internal climate will result from the interaction between B and its microclimate.

#### 4. THE BUILDING/ENVIRONMENT SYSTEM OF INTERACTION

The application of the building/environment (model of) interaction in design raises an important question: How do the 'surroundings' affect the performance of B? In other words, does  $E_{10}$  depend only on B or are there other factors affecting it which it would be necessary to consider at the design stage?

The fact that the climatic modification caused by the building is governed by physical laws of kinetic energy, radiative emission, thermal conduction, etc., leads us to regard the building/environment interaction as a system consisting /

consisting of the building, the environmental fields and a set of physical laws. The input of this system is the set of environmental fields in their initial state  $E_0$ , and its output is the set of environmental fields in their new, modified, state  $E_1$  (i.e.  $E_{10}$  and  $E_{1i}$ ).

However, this system is open to external influence in the sense that anything which influences the initial environment  $E_0$ , influences in turn the output of the system,  $E_1$ . The physical objects (buildings and landscape elements) in the immediate vicinity of the building are such external influences. Problems such as those associated with the wind or the shade around buildings must be solved at this relatively complex scale of interaction.

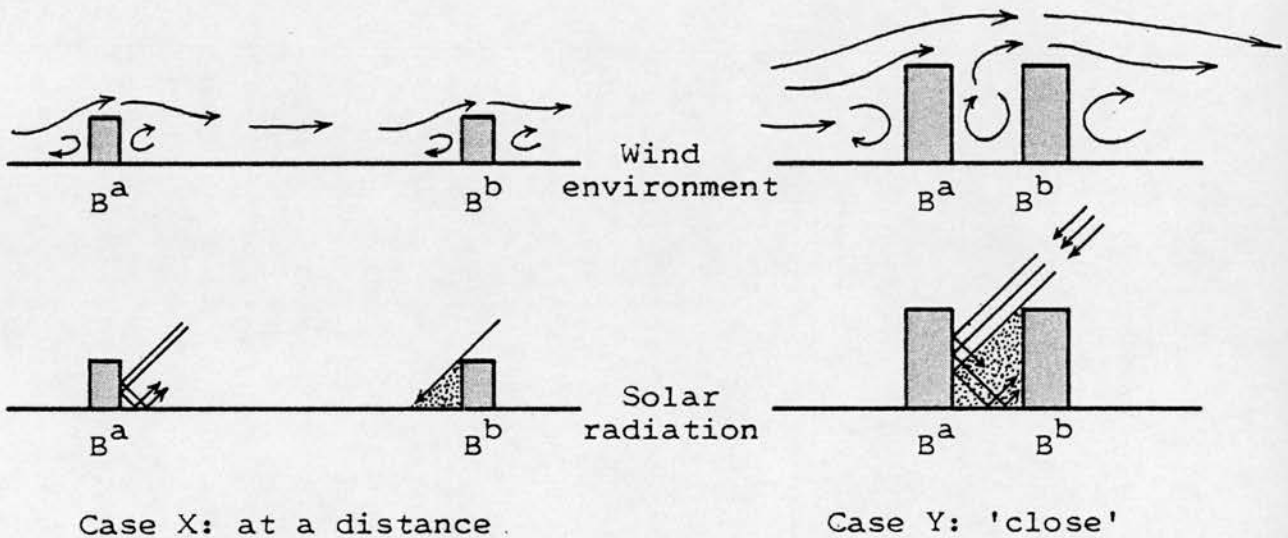
In order to achieve adequate prediction of the building performance during the design stage, it would be necessary to treat the interaction between the building and its environment as a sub-system in another higher-level system. The higher-level system to be considered in this context (which we shall call 'the System') deals with the interaction between the relevant group of buildings (to which the concerned building belongs), treated as a single built form, and its environment. Any reliable prediction of the building's performance depends on a study of the System. This can be done by following the climatic changes which take place in the System, in a chronological order relative to the development of the building, i.e. before and after the building exists.

We /

We begin by analysing the phenomenon of 'multiple' modification, i.e. the climatic modification caused by a group of buildings rather than a single building. We proceed then to describe the System of building/environment interaction as it concerns the architect.

#### 4.1 The Phenomenon of 'Multiple' Modification

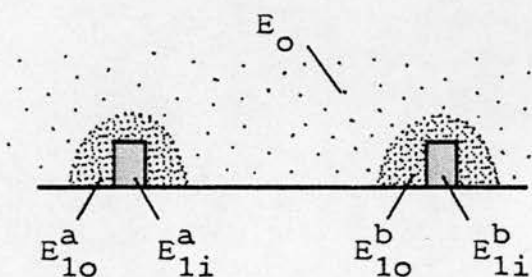
Buildings in physical proximity interact with one another via the micro-climate. In order to analyse such interaction, we may consider the case of two buildings,  $B^a$  and  $B^b$ ; first, separated at some distance (case X), and then micro-climatically 'close' to one another (case Y).



The essential difference between these two cases lies in the effect which the presence of each building has on the climatic performance of the other. Unlike case Y, in /

in case X each building, together with its own microclimate can be regarded as unaffected by the distant presence of the other building.

Thus: In case X, there are two sets of structural relations;



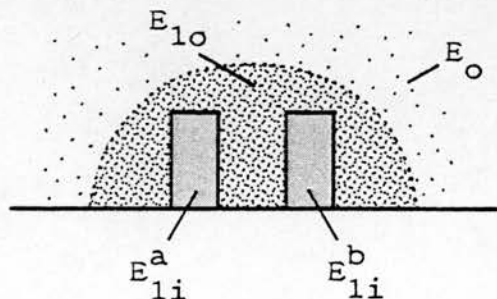
$$B^a(E_0) = E_{10}^a \quad (1.2.1)$$

$$B^a(E_{10}^a) = E_{1i}^a \quad (1.3.1)$$

$$B^b(E_0) = E_{10}^b \quad (1.2.2)$$

$$B^b(E_{10}^b) = E_{1i}^b \quad (1.3.2)$$

In case Y, the buildings interact and affect each other via the microclimate. For example, the wind flow affecting each building is the flow pattern for the group, which depends on the layout arrangement of the group including the particular characteristics of the form of the building under consideration. The whole group of buildings, treated as a single built form, interacts with the initial environment  $E_0$  to produce a microclimate  $E_{10}$  for the group. Each building in turn operates on this microclimate to produce its own internal climate. We then can write:



$$(B^a + B^b)(E_0) = E_{10} \quad (1.2.3)$$

$$B^a(E_{10}) = E_{1i}^a \quad (1.3.3)$$

$$B^b(E_{10}) = E_{1i}^b \quad (1.3.4)$$

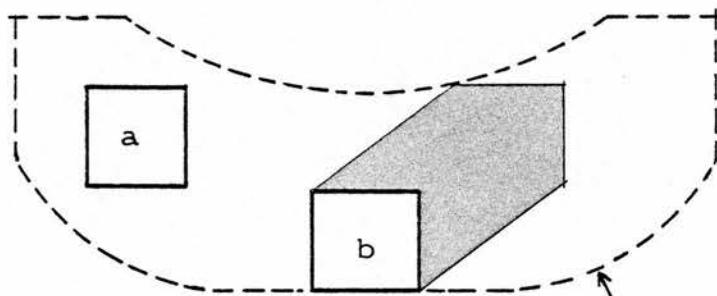
Here, /

Here, in case Y, the microclimate is produced by what we may call a process of multiple modification, in which each building participates through its own subsystem of interaction but the microclimate is governed by the interaction of the whole group with the initial environment  $E_0$ .

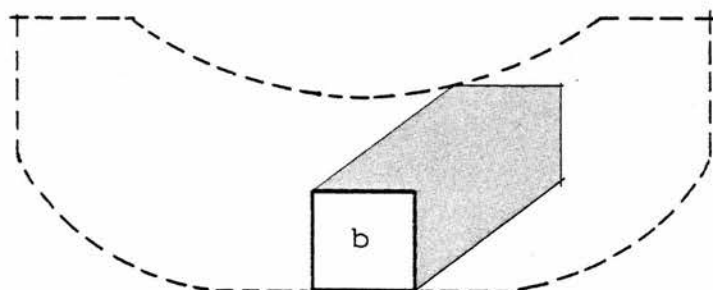
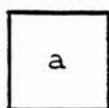
The performance of each building in this process depends on two independent factors: the climatic behaviour of the building's form and the spatial characteristics of this form within the layout of the group - the latter is a function of the form of the surroundings and the spatial relationship between the building's form and that of the surroundings.

A /

The performance of 'a' depends on the performance of 'ab' group.



A hypothetical projection of the shading pattern of 'b'.



The performance of 'a' is independent of the performance of 'b'.



A built form, isolated from its surroundings, i.e. 'no surroundings', possesses particular performance characteristics depending on its geometry and the physical properties of the construction material. The climatic behaviour of such a form has been expressed in sections 2 and 3 above in terms of the building/environment model of interaction. Placed in different parts of a city, within different contexts of surroundings, the same built form would perform differently in each place, and in no case would the performance correspond to the performance characteristics in the case of 'no surroundings'. This is analogous to the difference between studying the form's 'Subsystem' of interaction ~~with~~ the environment and the System it belongs to.

Most previous studies in this field are concerned with the investigation of behavioural characteristics of different forms in order to determine a so-called 'optimum' form (e.g. Olgyay, 1963). The question to ask is how such 'an optimum' form will perform in actual conditions, i.e. in a given context of surroundings, and whether it remains 'optimum'.

The piecemeal approach to the prediction of building performance, in which buildings are studied in isolation from their surroundings, has only a limited application in the development of our cities. The question that remains is: how to develop a more comprehensive approach to the study of climatic performance? The model of building/environment interaction /

interaction that we have set up (section 3.3) offers a framework within which to explore this question.

#### 4.2 Building/Environment System of Interaction

In this section we introduce a third building,  $B^C$  between  $B^a$  and  $B^b$ , in case Y, in order to see how the performance of this building is affected - this would be analogous to the problem confronting the architect during the design process.

Before  $B^C$ : For practical reasons we study the 'site climate',  $E_{OS}$ , in order to deduce from it a reliable picture of the climatic problems, rather than relying on the more general data of the regional climate. In case Y, the site climate  $E_{OS}$  is that part of the microclimate of the group which the architect needs to study during the design stage.

With reference to (1.2.3); if  $B^a + B^b = S$ , where S refers collectively to the surroundings, then we can write:

$$S(E_O) = E_{OS} \quad (1.4)$$

This means that the surroundings operate on the initial environment (regional or urban) to produce the site climate. Such a site climate bears no relation to the building in question,  $B^C$ , and prevails only until that building exists.

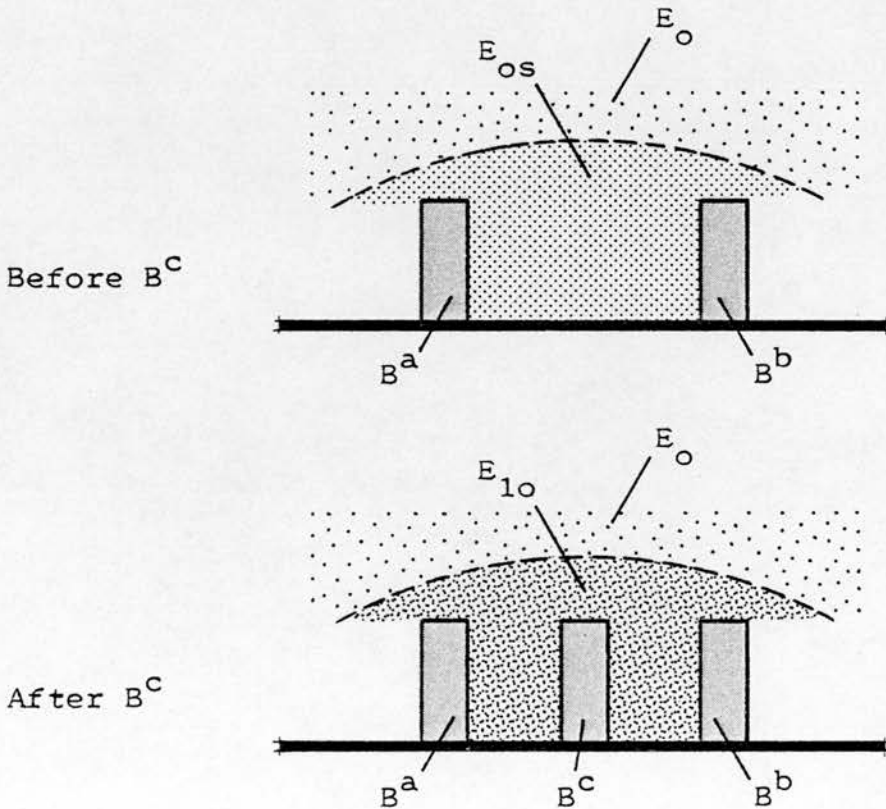
After  $B^C$ : In principle, the behaviour of  $B^C$  when placed /



placed between  $B^a$  and  $B^b$  can be described by saying that  $B^c$  operates on  $E_{os}$  (the site climate) to produce  $E_{1o}$ , new microclimate for the whole group. Thus we can write:

$$B^c(E_{os}) = E_{1o} \quad (1.5)$$

Implicit in this, is the effect of the surroundings,  $S$ , on  $E_{1o}$  which caused  $E_{os}$ , the site climate to differ from the initial environment,  $E_o$ , in the first place. This, however, does not give a useful picture of the prediction of either  $E_{1o}$  or the performance of  $B$ . Practically it would not be possible to deduce  $E_{1o}$  in this way. One cannot for instance add the wind flow around  $B^c$  to the micro-wind of /



of S, but rather  $B^C$  and S must be studied as a single built form.

We need, therefore, to make explicit the combined effect of  $B^C$  and S (i.e.  $B^a + B^b$ ) on the microclimate,  $E_{10}$ . Thus, we can express the behaviour of  $B^C$  in this context by writing:

$$(B + S) (E_o) = E_{10} \quad (1.6)$$

(where we have written B to mean  $B^C$  to make this a general relation).

This means that the building and its surroundings acting together operate on the initial environment (regional or urban) to produce the microclimate for the group. The building in turn operates on this microclimate to produce its internal climate. In order to make reliable prediction of the building performance, we have to study the behaviour of the building in this context.

#### 4.2.1 The System

We now have a number of relations which describe the System of interaction between the building and its environment:

Before /

$$\text{Before B:} \quad S(E_o) = E_{os} \quad (1.4)$$

---


$$\text{After B:} \quad (B + S)(E_o) = E_{1o} \quad (1.6)$$

$$B(E_{1o}) = E_{1i} \quad (1.3)$$

$$E_{1o}(H) = H_+ \quad (2.1)$$

$$E_{1i}(H) = H_+ \quad (2.2)$$

$$E_1(B) = B \quad (3)$$

The study of this System would enable the architect to construct, through a series of predictions ( (1.6) and (1.3) ), a reliable picture of the building's environmental performance and evaluate it against the requirements of satisfactory performance ( (2.1), (2.2) and (3) ). He would also be able to control the design process of B towards achieving a satisfactory solution by studying the difference between the site climate, (1.4) and the building's microclimate, (1.6), each time a form for B is proposed, i.e. knowledge of the site climate helps in giving the architect an orientation towards a satisfactory solution.<sup>1</sup>

Furthermore, (1.6) and (1.3) illustrate how the building's microclimate provides the link between the surroundings S and the internal climate  $E_{1i}$ .<sup>2</sup> This indirect effect /

- 
1. An Interactive Climatic Design Process, based on the building/environment system of interaction is developed in the following Chapter (Chapter 5).
  2. It also provides the link between the design of B under consideration and the internal climate of the surrounding buildings, though this is not the fundamental issue in this study.

effect of S on  $E_{1i}$  depends on the spatial relationship between B and S, which must be controlled in order to avoid the negative effect it will otherwise have on  $E_{1i}$  as well as  $E_{10}$ .

Fortunately, the functional requirements of  $E_{10}$  and  $E_{1i}$  are not in conflict. In a hot climate, a 'shady' environment outside the building, for example, reduces the thermal impacts on a human out-of-doors and provides less thermal problems for B than a 'sunny' environment. It is therefore favoured by people outside the building as well as by people inside the building. The opposite applies in cold climates. This is an important feature which gives a solid foundation to any attempt to control the building's microclimate by the means available to the architect, including the 'enhancement' of the building's climatic modification through a rational adaptation of the form of the building to suit the form of its surroundings.

##### 5. THE 'ENHANCEMENT' OF THE BUILDING'S CLIMATIC MODIFICATIONS

The fact that the physical performance of a building is linked to its spatial relationship to the surroundings leads one to emphasise the importance of studying the form of a building in the context of its surroundings.

Given a problem with known 'surrounding' conditions, the architect's task would be to ensure a form which brings the /

the microclimate  $E_{10}$  closer to the internal climate  $E_{1i}$ . The surroundings in this matter play an important role - they can either diminish or magnify an effect a building has on its environment. The architect should therefore be able to magnify advantageous climatic conditions and/or diminish deleterious conditions, so as to enhance the satisfactoriness of the environment, by modifying the relationship between the building's form and its surroundings.

The effect of a building on its environment is governed, as mentioned earlier, by physical laws and in most cases (except in ideal climatic conditions) such an effect is limited to bridging the gap which normally exists between the 'natural' climate and a satisfactory 'built' climate.

Given this limited capacity, and the 'independence' of the building's climatic behaviour from its relation to its surroundings (see section 4.1), this study introduces the principle of enhanced climatic modification.

This principle embodies the fact that the building/surrounding spatial relationship can contribute to (instead of hindering) the performance of a built form in producing a satisfactory micro-climate and internal climatic conditions. The principle is based on the phenomenon of multiple modification (discussed above in sec. 4.1), in which the microclimate of a building depends on the form of the building, the form of the surroundings and the spatial relationship between the building's form and that of the surroundings.

The /



The application of this principle in design practice requires the architect to treat the building/environment interaction as a subsystem open to external influences of a higher-order System. In studying the System, the architect must consider three main points:

- a) Effective microclimatic control is a function of the design of buildings, which has economic as well as functional gains.
- b) The spatial relationship between the building under design and its surroundings is the means of micro-climatic control.
- c) A correct building/surrounding relationship is a component in any satisfactory solution of the climatic design of the building.

## 6. SUMMARY AND CONCLUSIONS

An attempt was made in this Chapter to analyse the interaction between the building and its environment and indicate aspects which are fundamental to the climatic design of buildings.

A formal theory of building/environment interaction (Wilson, 1973; Lord and Wilson, 1980) which establishes the principles of the relationships between man, building and environment, has been discussed. Elaboration of this theory made it possible to underline the building's micro-climate within the structural relationships of the interaction. This /

This enabled us to develop the climatic behaviour of the building by indicating that the building interacts with its environment to produce its own microclimate, and operates on this microclimate to produce its internal climate. This inevitably has a structural effect on the design process of the building (the subject of the following chapter).

Having made the interdependence of the microclimate and design explicit, it was important to establish a framework within which to study the performance of a building during the design stage. Articulation of the building's microclimate made it possible to describe the System of interaction which includes the effect of surroundings on the microclimate of a building, and which it would be necessary to consider in order to achieve a reliable prediction of the building performance. This has been analysed in the context of what is called 'the phenomenon of multiple modification'.

Consequently, it was considered a principle in climatic design that the form of a building should be rationally adapted to suit the form of its surroundings, so as to produce a combined effect which enhances the satisfactoriness of the environment being controlled.



CHAPTER VDEVELOPMENT OF AN INTERACTIVE  
CLIMATIC DESIGN PROCESSCONTENTS

1. INTRODUCTION
2. NOTES ON THE OVERALL DESIGN PROCESS
  - 2.1 The Vertical Structure
  - 2.2 The Horizontal Structure
3. THE CONCEPTUAL FRAMEWORK OF AN INTERACTIVE APPROACH
4. PRACTICAL SIMPLIFICATION
  - 4.1 Shape, Fabric, and Building Performance
5. WIND, SUN, AND BUILDING SHAPE
6. THE STRUCTURE OF INTERACTIVE CLIMATIC DESIGN PROCESS
7. SUMMARY AND CONCLUSIONS

## 1. INTRODUCTION

The analysis of building/environment interaction, which was conducted in the preceding Chapter, provides the theoretical basis for an interactive approach to the climatic planning and design of buildings. In this Chapter, the aim is to develop the structure of this approach and establish the principles of its application in design practice.

This is achieved by embedding the structure of the building/environment System of interaction (see Chapter 4, Section 4.2.1) in the overall design process of the building.

We begin with a review of the overall design process. A framework is then established for the interactive approach, using the structural relationships of the interaction between the building and its environment. The framework is further developed into an extended structure of what we may call the interactive climatic design process.

## 2. NOTES ON THE OVERALL DESIGN PROCESS

The design process is the structuring of the sequence of the events which are necessary to transform a brief into a design of a built form. The process comprises a number of decision-making activities which are seen as steps progressing from the abstract and general at the start, to the specific and concrete as the design nears completion.

In /

In each step the architect deals with a sub-problem within the total problem, and a design decision is undertaken. The steps may be grouped into a "vertical structure" of stages each of which has a different aim, while the "decision sequence" in each step is a more or less uniform "horizontal structure".

Some existing descriptions of design procedure (RIBA, 1973, Asimow, 1962, Archer, 1969) are extended to include the construction (or production) phase of end products (see Table 1). Here, we restrict the design process to the designing phase of a building.<sup>1</sup>

## 2.1 The Vertical Structure

Thornley's "Method" (cited by Broadbent, 1973, p.265) contains four stages which are typical of the vertical structure of the design process. As Table 2 shows, two of these stages are central to the act of designing; these are: "The Isolation of a General Concept of 'Form'" and "The Development of the 'Form' into the Final Scheme". They are equivalent to the two-stage design procedure which Hillier and Leaman (1974) discuss, and which distinguishes between "strategic" and "tactical" design. The first, maps "from a statement of the problem [the brief] into a general solution. The second maps from a general solution to a particular solution" (ibid, p.9).

Fig. 1 /

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1. Although some of what takes place on the site during construction may require going back to the drawing table it is understood in this study that an effective design process should not allow this to happen.

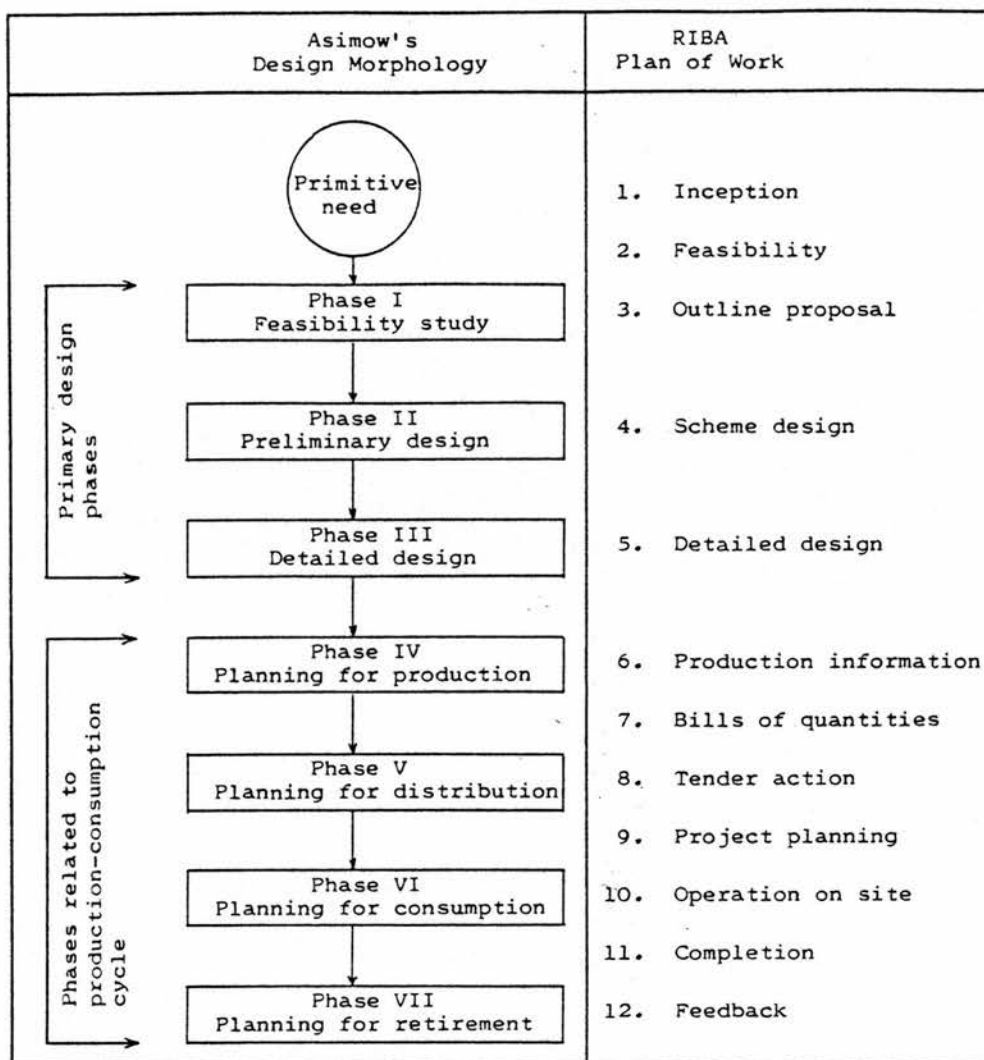


Table 1: Examples of Design Procedure  
(from: Asimow, 1962, p.12,  
RIBA, 1973, p.349).

Stage	
1.	The Accumulation of Data
2.	The isolation of a General Concept or 'Form'-
	(a) The Essential Purpose of the building
	(b) The Relationship of the Building to the Individual
	(c) The Relationship of the Building and its Occupants to the Surrounding Social and Commercial Pattern
	(d) The Relationship of the Building to its Physical Surroundings
	(e) Economics
	(f) Preliminary Consideration of Spatial and Formal Organization
	(g) Preliminary Consideration of Structural Organization
	(h) The Establishment of an appropriate 'Form' or Generalized Concept
3.	The Development of the 'Form' into the Final Scheme-
	(a) Detailed Consideration of Spatial and Formal Organization
	(b) Detailed Consideration of Structure
	(c) The Development of Architectural Values
4.	The Presentation of the Final Scheme.

Table 2: Thornely's four-stage design process  
(from: Broadbent, 1973, p.265).

Fig. 1 shows the vertical structure in a diagrammatic form, and for convenience the four stages are termed Briefing and Site Analysis, Scheme Design, Detail Design, and Production of Working Drawings.

At the start of the design process the architect is presented with a brief which, normally, contains information not about a built form but rather about functions which a future building is expected to perform. The brief represents a problem situation known to the architect to embody a cluster of interacting sub-problems; neither the sub-problems nor their structure is unequivocally stated. In such a case, the architect's task is "finding as well as solving problems" (Lawson, B., 1980, p. 87).

Site analysis enables the architect to understand some of the design constraints (topographical, climatic, legal, etc.), which are in most cases imposed by "uncontrollable variables", and which influence some of the individual and particular characteristics of the design. This is the first step towards establishing limits, possibilities and criteria.

The design strategy normally employed by the architect enables the search for a solution and the problem specification to "proceed side by side ..." (Hillier et.al., 1972, p.17). There is a "... vast variety of design decisions [which] cannot be taken ... before the solution in principle is known" (ibid, p.16). The architect, therefore, learns about /

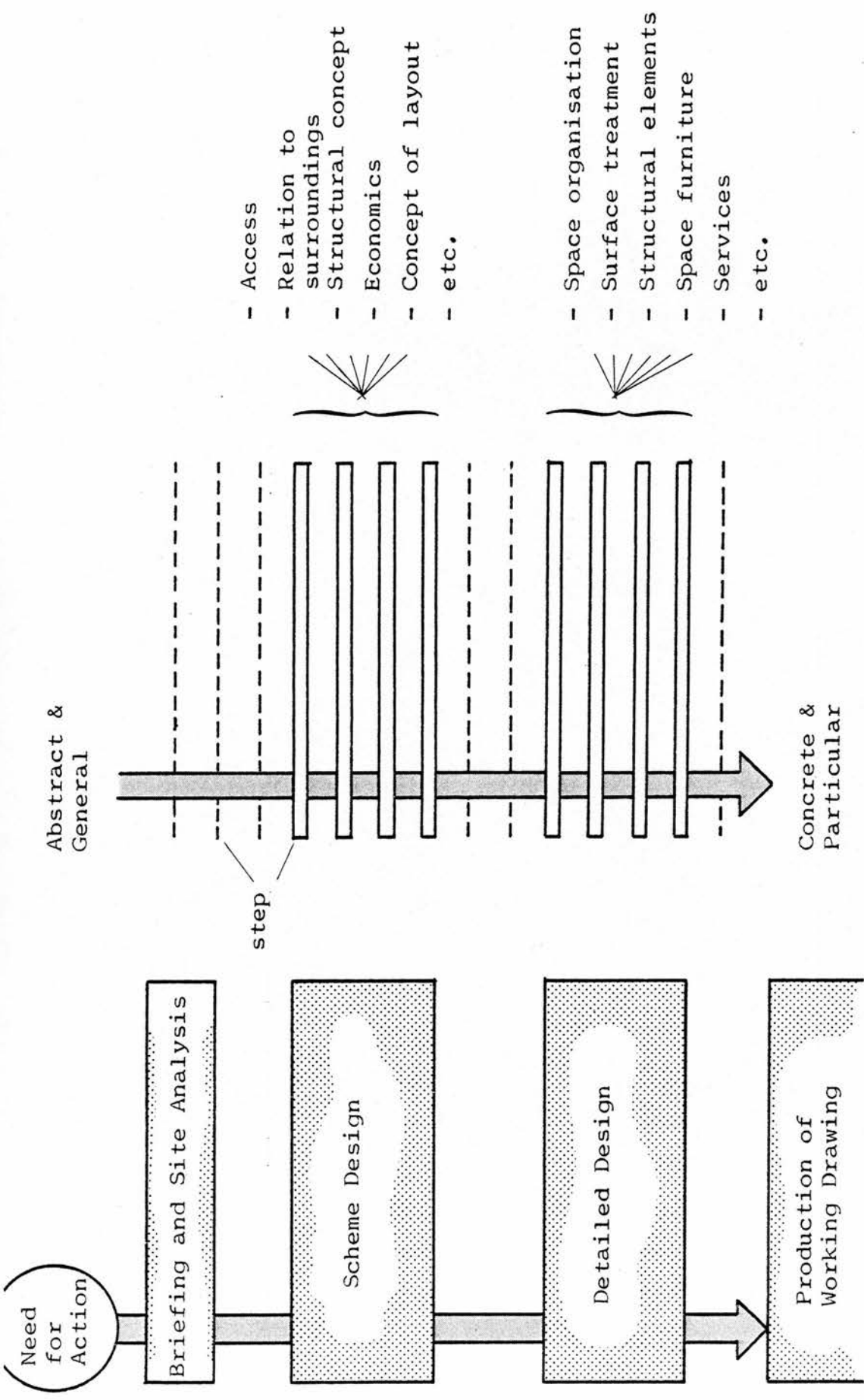


Fig. 1: The vertical structure of the design process

about design problems by developing and testing tentative solutions. In this process, decisions which have wide ranging effects are taken prior to those which have more limited influence (Lawson, 1975).

At the Scheme Design stage, the architect deals with general problems. Aspects such as the building's spatial, social and aesthetic relationships to its surroundings, the strategy for the organization of internal space, the strategy of the structural system, etc., are studied in order to develop a design concept which portrays the general character of the built form. It is at this stage that the shape and orientation of the form are determined.

At the Detail Design stage, more specific problems are dealt with. These problems include the fabric properties of the building's envelope (the construction materials) and the design of windows, as well as the design of structural elements, lighting, heating, surface treatment, etc.

Some of the decisions of the detail design stage (e.g. the design of shading devices) may be extended into the Production of Working Drawings. Although Fig. 1 shows no such overlap between the stages it is understood that 'vertical' feedback loops may take place though these are not mentioned in order to simplify the argument.

## 2.2 The Horizontal Structure

The 'decision sequence' of the design process which the architect follows in solving sub-problems consists of three /



three basic parts: An information input, a decision-making process, and an information output, with a possible feedback loop (see Fig.2).

The input is information embodying the sub-problem situation and might include site data, performance specifications, previous 'outputs', etc. The output is another class of information describing components of built form (drawings, specifications, etc.).

The decision-making process is, in some cases, a mental activity - "Black Box" (Jones, 1981) - in which the architect relies on intuition and past experience to come up with a solution to the problem at hand. Other cases, especially /

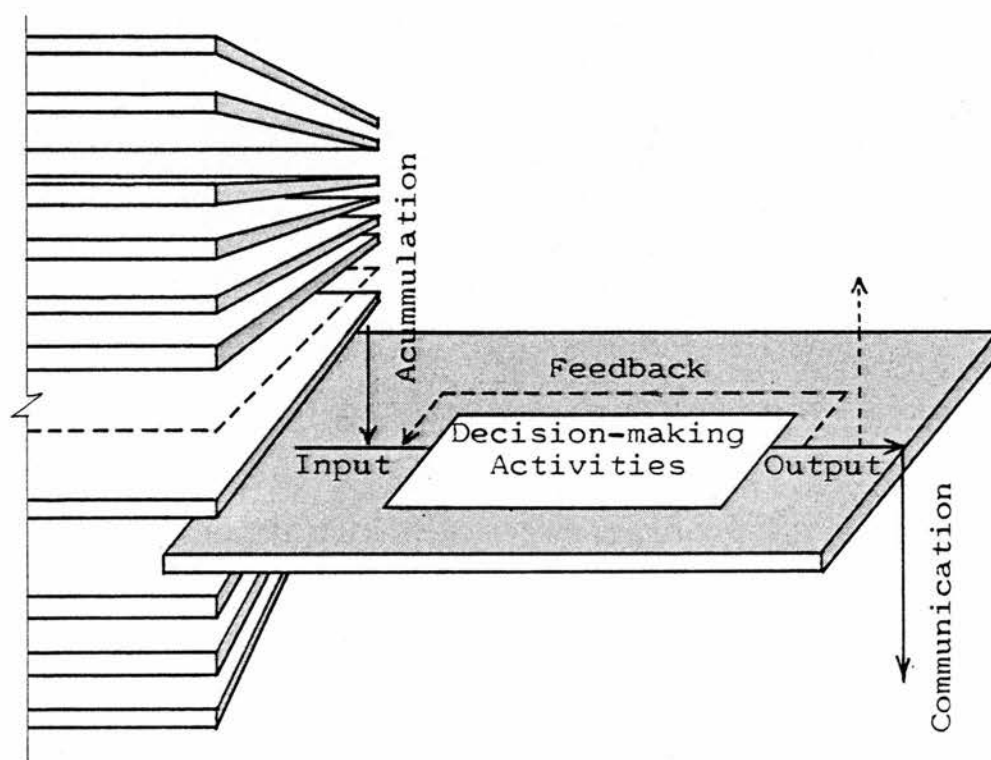


Fig. 2: The horizontal structure of the design process

especially when dealing with interacting sub-problems may need to be defined explicitly, i.e. as a "Glass Box", in order to make designing more manageable and allow the architect to provide himself with knowledge and experience he otherwise lacks.

- |   |
|---|
| 1 - The identification of design parameters   |
| 2 - The identification of independent variables                                     |
| 3 - The identification of dependent variables                                       |
| 4 - The identification of relationships among parameters and variables              |
| 5 - The prediction of values of independent variables                               |
| 6 - The identification of constraints governing dependent variables                 |
| 7 - The identification of constraints governing design parameters                   |
| 8 - The identification of values of design parameters                               |
| 9 - The identification of expected values of dependent variables                    |
| 10 - The investigation of the consistency of values, relationships, and constraints |
| 11 - The comparison of, and selection from, alternative sets of parameter values.   |

Table 3: An example of the structure of decision-making process (from: Levin, 1966)

Whether the decisions are made intuitively or in a consciously systematic way, the architect is required to ensure that the building as designed will perform as expected./

expected. Levin (1966) introduces a structure of the decision-making process which enables the architect to develop solutions based on knowledge of building performance<sup>1</sup> (see Table 3).

### 3. THE CONCEPTUAL FRAMEWORK OF AN INTERACTIVE APPROACH

The structure of the interaction between a building and its environment indicates that the environment cannot be treated as an 'independent' variable during the design process of the building.

As mentioned earlier (in Ch. 4), the building interacts with its microclimate to produce the internal climate. The problem is that the design of the building is expected to relate to the building's microclimate, but this microclimate depends on the design.

This problematic relationship between the design and the microclimate requires the design process to incorporate a 'feedback' mechanism. In other words, the structure of the climatic design process of the building must allow the architect /

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1. 'Performance appraisal' on different accounts (climatic, behavioural, economic) is discussed by Markus (1969) and is shown to be relevant as a generative as well as an evaluative technique during the design process.

architect to make predictions at certain stages of the process, and to respond to the outcome of the prediction process by design modifications.

This structure implies a design process proceeding by 'successive approximation', the principles of which can be described in the light of the analysis of building/environment interaction made in the preceding chapter (Ch.4).

By choosing to describe the initial environment,  $E_o$ , in terms of  $E_{os}$  i.e. the 'site climate', the climatic behaviour of a building, as expressed earlier, (1), can be expressed, in principle, as:

$$B(E_{os}) = E_1 \quad (1.7)$$

(where  $E_1 = E_{1o} + E_{1i}$  (4)).

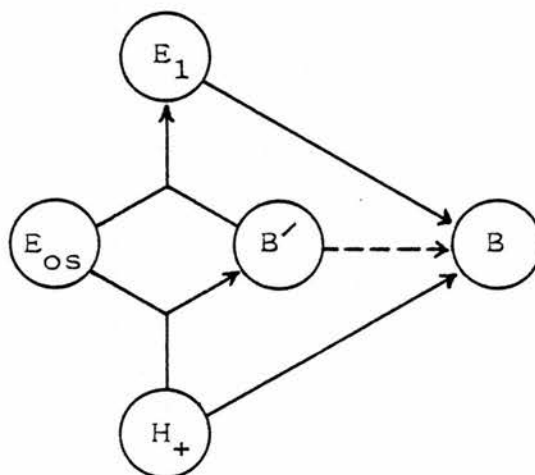


Fig. 3:

The concept of  
'successive approximation'  
of the climatic design process  
of B.

Accordingly, /

Accordingly, the conceptual framework of designing by successive approximation (see Fig.3) can be described in the following way.

The first step, would be to develop an initial idea of the built form,  $B'$ , on the basis of knowledge of the site climate,  $E_{os}$ , and human requirements, (Fig.3a). The second step, would be to predict the new environment,  $E_1$  (Fig.3b). The third step, would be to use the prediction of  $E_1$  to develop the final form of the building,  $B$ , which satisfactorily meets human needs (Fig.3c).

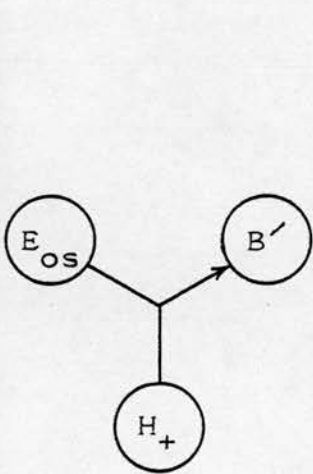


Fig. 3a:  
 $B'$  is an initial  
idea of built  
form.

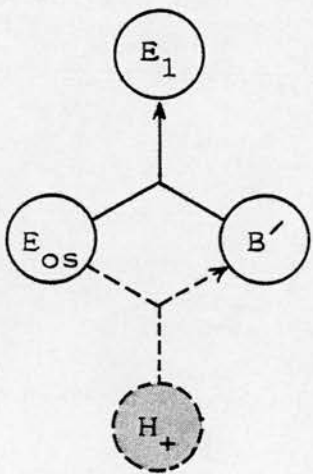


Fig. 3b:  
Prediction of  
the new  
environment  $E_1$ .

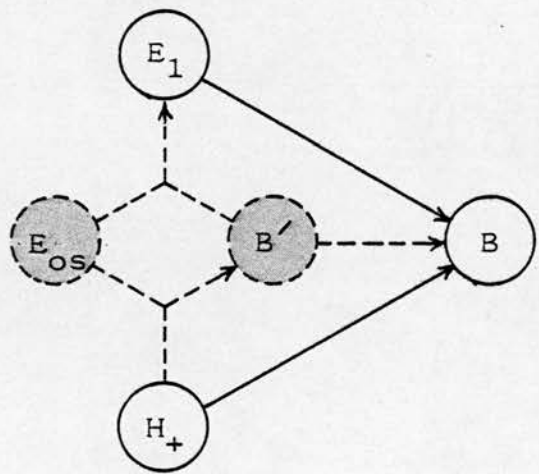


Fig. 3c:  
 $B$  is the final design  
of the built form.

Practically /

Practically, however, a complex situation may arise: any change in the built form i.e.  $B' \rightarrow B$ , is accompanied by a change in the new environment,  $E_1$  and would require a repetition of the prediction of  $E_1$ . This puts the design process in an open-ended situation.

This framework requires, therefore, further elaboration and refinement in order to be useful in proposing actual design practices.

#### 4. PRACTICAL SIMPLIFICATION

The design, whether the initial  $B'$  or the final  $B$ , must be based on knowledge of performance. Prediction and appraisal of the environmental performance of buildings during the design process is a complex task in itself, because of the large number of design parameters involved and the wide range of environmental conditions to which buildings are normally subjected. The task becomes tractable through selection of the performance parameters that are to be regarded as of prime importance, and the restriction of attention to the design parameters and environmental information that influence them. That is, performance prediction during the design process can be made on the basis of a simplified description of the building/environment system (or sub-systems) of interaction.

In view of the discussion in Chapter 4, there are two structural /



structural relationships in the System, which are of immediate concern:

$$(B + S)(E_o) = E_{1o} \quad (1.6)$$

$$B(E_{1o}) = E_{1i} \quad (1.3)$$

And they are referred to here as sub-system 1 and sub-system 2, respectively.

The alteration of independent and dependent variables in these two sub-systems is of particular interest and requires to be emphasised.

As Table 4 indicates, the 'surroundings', S, and the initial environment,  $E_o$ , are independent variables operating in sub-system 1, while  $E_{1i}$ , the internal climate, is the dependent variable in sub-system 2. The crucial issue is that the dependent variable in sub-system 1 (i.e. the micro-climate,  $E_{1o}$ ) becomes an independent variable in sub-system 2.

	Independent variables	Dependent variables
Sub-system 1	S & $E_o$	$E_{1o}$
Sub-system 2	$E_{1o}$	$E_{1i}$

Table 4: The flow pattern of climatic information in building/environment System of interaction.

Thus, /



Thus, one approach to the simplification of the System description would be to isolate those parameters of the built form which mainly influence the microclimate in sub-system 1, from those which mainly influence only the internal climate in sub-system 2. A further simplification would be to isolate those variables of the microclimate which are particularly sensitive to changes of the chosen parameters of the form.

One is thus led to a process in which microclimatic variables are controlled by adjusting the values of one set of form parameters, and, subsequently the internal climate is controlled by adjusting the values of a different set of form parameters. By means of such a duplex structure of the performance prediction process, the complex task of performance prediction is rendered more manageable.

#### 4.1 Shape, Fabric, and Building Performance

The first of the assumed simplifications that we shall discuss is the distinction that can be made between the effect on building performance of Shape and Fabric.

The form of a building is defined by its shape and fabric characteristics. The shape is described by the geometrical parameters of the built form i.e. height, length, orientation, configuration, etc. The fabric is described by the physical properties of building materials (heat capacity, thermal conductivity, surface coefficients, etc.) and their spatial organisation (e.g. area and distribution of glass, cavity walls).

Each of the shape parameters, and the fabric properties of a built form affects both the form's microclimate and its internal climate. In practice, however, the effects are not of equal significance. The effect of any one parameter depends on the design of the particular form under consideration. In some cases, such as in mirror-glazed buildings, the fabric may cause an appreciable effect on the radiation field in the microclimate<sup>1</sup>. But, in most cases, fabric properties will have relatively little effect on the radiation field (and none at all on wind-flow) in the microclimate, which will be determined by the geometry of the shape of the building (and its surroundings).

The fact that wind-flow characteristics and the solar radiation distribution in the microclimate of buildings depend only on the shape of built forms makes it reasonable to assume that the shape/microclimate relationship dominates sub-system 1, and therefore would be given prime consideration in predicting building performance during the design stage. The shape/performance relationship in the microclimate depends, of course, on the spatial relationships between the form and its surroundings (see Chapter 4, sec. 4.1).

This/

---

1. see, for example, Aynsley, 1979.

This is a practical assumption which allows us to specify the two sub-systems which were mentioned above as follows:

$$\text{sub-system 1 } (B_s + S_s)(E_o) = E_{1o} \quad (1.8)$$

$$\text{sub-system 2 } (B_f + B_s)(E_{1o}) = E_{1i} \quad (1.9)$$

where  $B_s$  and  $B_f$ , refer to the Shape and fabric parameters of the built form under design, respectively; and  $S_s$ , refers to the shape characteristics of surroundings.

This refinement sacrifices the optimization of the shape/internal climate relationship. It does not mean, however, overlooking the effect of shape on the internal climate, but rather the 'optimization' of the internal climate could be achieved by manipulating the design of the fabric within limits set up by a micro-climatically defined shape.

Table 5, shows the information flow pattern which it would be necessary to consider during the prediction process of building performance. In addition to the pattern of flow of microclimatic information discussed earlier, the shape parameters of the form, which are design parameters in sub-system 1, become independent variables in sub-system 2.



$(B_s + S_s)(E_o) = E_{1o}$	$(B_f + B_s)(E_{1o}) = E_{1i}$
$.B_s$ : shape-parameters of B	$.B_f$ : fabric-parameters of B
$.S_s$ : shape-parameters of S	$.B_s$ : shape-parameters of B
$.E_o$ : the initial environment	$.E_{1o}$ : the micro-climate
$.E_{1o}$ : the micro-climate	$.E_{1i}$ : the internal climate

Table (5): The information-flow pattern in interactive climatic design

THE SUB-SYSTEM

DESIGN PARAMETERS

INDEPENDENT VARIABLES

DEPENDENT VARIABLES

## 5. WIND, SUN, AND BUILDING SHAPE

The second argument for the proposed simplification of the building/environment System description, relates to the establishing of criteria for an acceptable microclimate on the basis of the nature of the shape/microclimate relationship.

The microclimate has a function; and its variables vary in their sensitivity to changes of the shape parameters and in their predictability. These three aspects (function, sensitivity and predictability) determine how to establish such criteria.<sup>1</sup>

Sensitivity and predictability: Air temperature and vapour pressure in the microclimate around a building are modified, indirectly, by the shape of the built form in response to their interdependence on 'micro-wind' and 'micro-sun' conditions which (the latter) are directly modified by the shape parameters.<sup>2</sup> Also, with the currently available predictive techniques, whether of conventional or computer-based methods, it is far easier to study, predict, and hence control the wind and sun in the microclimate of/

- 
1. The last two aspects, though mentioned only briefly here, are discussed later in Ch. 7.
  2. The fabric properties may have direct influence on air temperature and vapour pressure, though not considered because of the distinction made above between the effect of Shape and Fabric, (see section 4.1).

of a proposed building layout, than any other micro-climatic variables.

But the more important aspect which distinguishes the wind and the sun, and makes the shape/wind and shape/sun relationships even more critical is that of function.

The microclimate affects the physical and physiological well-being of people and influences their use of the external space. People may have a wide range of physiological and personal adaptation mechanisms but they are easily discouraged and even prevented from using the external space (whether it is the private 'backyard' or the public street) by adverse microclimatic conditions of wind and sun, in particular.

Also, the microclimate affects the climatic performance of the building in the internal space. The building's thermal performance, for example, depends on the irradiation load falling on the external surfaces, and is affected by the wind-speed external to the surface. "Wind-mediated" heat loss by air infiltration depends also on the wind speed around the building. These are problems which are directly attributed to 'micro-wind' and 'micro-sun' conditions in the external spaces around buildings.

An 'optimum' microclimate would have to be defined in terms of the relationship between these two kinds of effect. So far, the literature is lacking such definition, and /



and the attempt to establish it lies outside the scope of this study.<sup>1</sup>

However, some insight into the relationship between the effects of the microclimate on people and buildings offers a logical alternative to an 'optimum' microclimate.

The three variables of such a relationship, which are of immediate concern, are the initial environment,  $E_o$  (whether it is the 'site' climate or the 'regional' or 'urban' climate), the building's microclimate,  $E_{10}$ , and the internal climate,  $E_{1i}$ .

The hypothesis which this study follows regarding an acceptable microclimate is this: 'what is good for people is good for buildings'. Put formally, this means that an adequate microclimate for people, nearer to their needs than the regional climate, is also an advantage for the building performance in the internal climate, which is for people too.

Having /

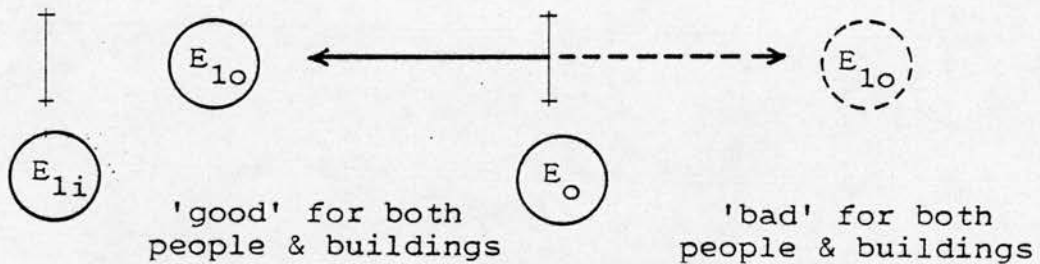
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1. 'Optimization' is, in general a limiting approach to building design due to the multi-disciplinary nature of building functions; see for example Hillier et al, 1972, Hillier and Leaman, 1972. On the shortcomings of 'optimization' regarding the environmental performance of buildings see Helmy, 1978.



Having established, previously, that the building mediates between  $E_{10}$  and  $E_{1i}$ , one can reasonably assume that the 'better'  $E_{10}$  is for people in the external space, the less the stress on B in producing a satisfactory  $E_{1i}$  (for humans). Elementary to this argument is that the 'bigger' the difference between  $E_{1i}$  and  $E_{10}$ , the greater the stress on B, i.e. the larger the task for B.

This means that the nearer  $E_{10}$  is to  $E_{1i}$  - which generally means the further  $E_{10}$  is from  $E_0$  towards  $E_{1i}$ , the better.



This last point was mentioned when we discussed the principle of 'enhanced' climatic modifications (Chapter 4) where it was indicated that the architect should, by modifying the spatial relationship between the building and its surroundings, "bring  $E_{10}$  closer, than  $E_0$ , to  $E_{1i}$ ".

The /

The measure of acceptability of the microclimate, therefore, would be dependent on the use pattern of the external space, and would be influenced by the cumulative effect of the wind and sun on people's response to them. This is in line with the assumption made above, (section 4.1), which distinguished the shape/microclimate relationship and which is made exclusively on the basis of shape/wind and shape/sun relationships.

## 6. THE STRUCTURE OF INTERACTIVE CLIMATIC DESIGN PROCESS

It is now possible to develop the structure of interactive climatic design process on the basis of the assumed description of the building/environment system of interaction.

The interactive process is basically a two-stage procedure in a 'vertical structure', the time order of which is critical to its success (see Fig.4). Each stage is a complete 'decision sequence' (in a 'horizontal structure') dealing with a particular sub-system of the building/environment system of interaction.

Stage 1, coincides with the Scheme Design stage where an overall design concept of the proposed built form is considered. It deals with sub-system 1:

$$(B_s + S_s) (E_o) = E_{10} \quad (1.8)$$

The /

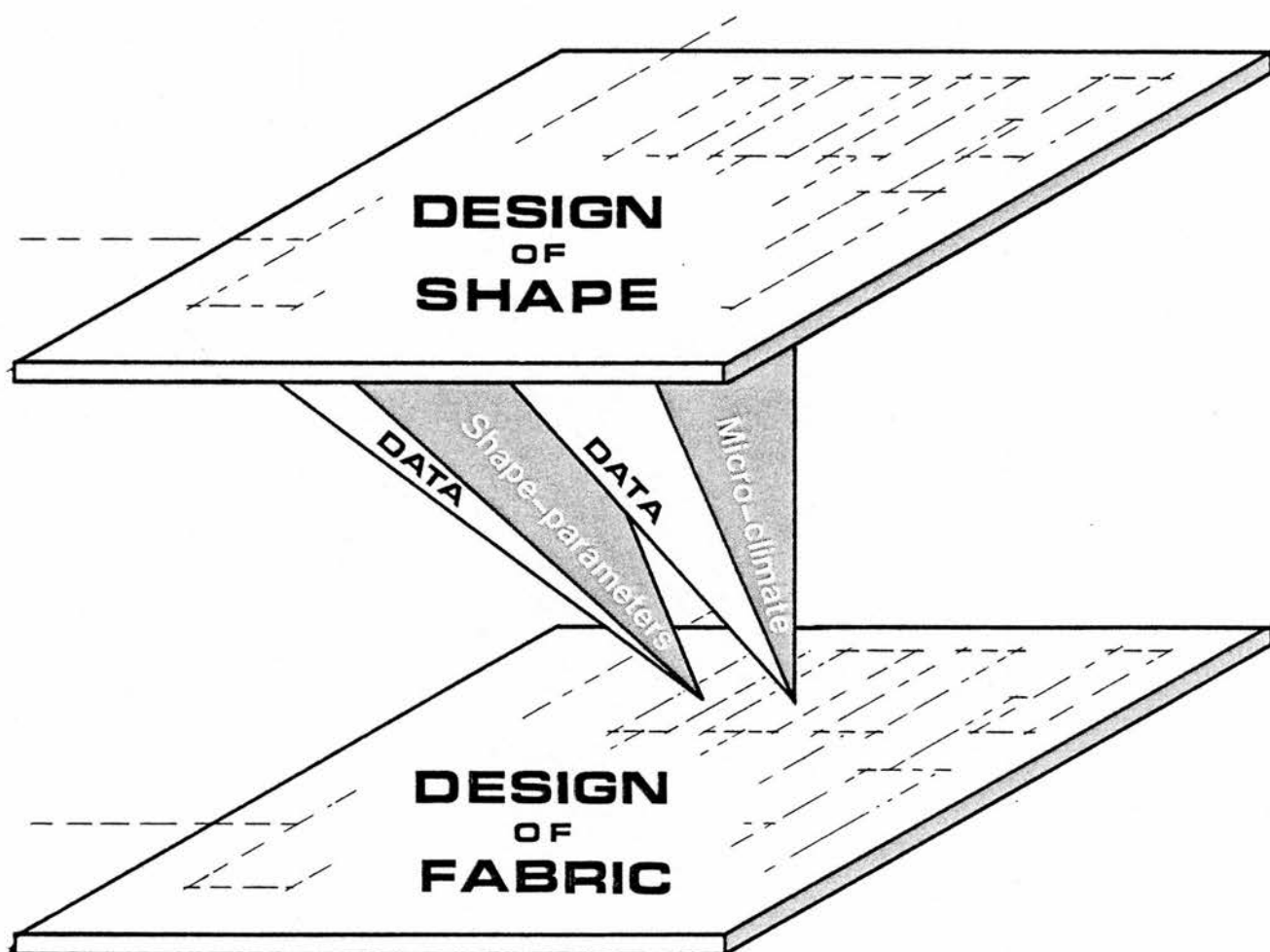


Fig. 4: A two-stage interactive climatic design process (vertical structure)

The task of the architect at this stage (Stage 1) would be to control the microclimate  $E_{10}$  by means of the design of the building shape,  $B_s$ , taking into consideration the effect of the 'shape' of the surroundings,  $S_s$ , on this microclimate.

In postulating tentative solutions there would be two aspects guiding the architect's thought: First, knowledge of the site climate, as influenced by the surroundings (see (1.4), Chapter 4) provides the starting point for synthesis. Such knowledge may indicate which areas are, for example, obscured most of the time from the sun's rays, or what sort of wind problems would be expected in the microclimate, and so on.

Secondly, and this is where he would need the support of systematic morphological studies<sup>1</sup>, predetermined knowledge of the "characteristic behaviour patterns" in the relationships between micro-wind or micro-sun and shape parameters, guides the architect's search for an acceptable range of solutions for the building shape. He will be changing height, length, orientation, trying to 'fit' his building into the best possible relation to the surroundings.

These design decisions, however, develop gradually. In searching for a range of solutions for  $B_s$ , the architect deduces logical predictions of the corresponding microclimates, and /

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1. discussed later in Ch.7.

and may resort to subjective assessment using terms like 'acceptable', 'tolerable' or 'unacceptable' to describe them and pass judgement on the design's performance.

The decision to accept a design concept for  $B_s$  would be made on the basis of a test-model in order to ensure, by objective assessment, the attainment of an acceptable microclimate. The use of simulation techniques is necessary at this level of decision-making.<sup>1</sup> It would also enable the architect to assemble microclimatic data which would be needed in Stage-2. The structure of the underlying decision-making process is shown in Fig.5.

It indicates that, with the help of simulation techniques and the identification of values of the shape parameters of both the building and its surroundings, combined with information about the regional (or urban) climate, the architect should be able to embody sub-system 1 in a suitable form of representation. By predicting the microclimate and evaluating it against a predetermined measure of acceptability, the architect would be in a position to ensure acceptable design performance. The embodiment of the sub-system should be flexible enough to allow easy changes of the shape parameters to be made whenever the evaluation process requires the architect to do so. In terms of the conventional methods of simulation techniques (e.g. the 'wind-tunnel' or the 'heliodon') this means that the blocks representing built forms must accept change, both in their layout arrangement and in their major details (e.g. roof, overhangs). The simulation of the effects of such /

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1. See Chapter 7.

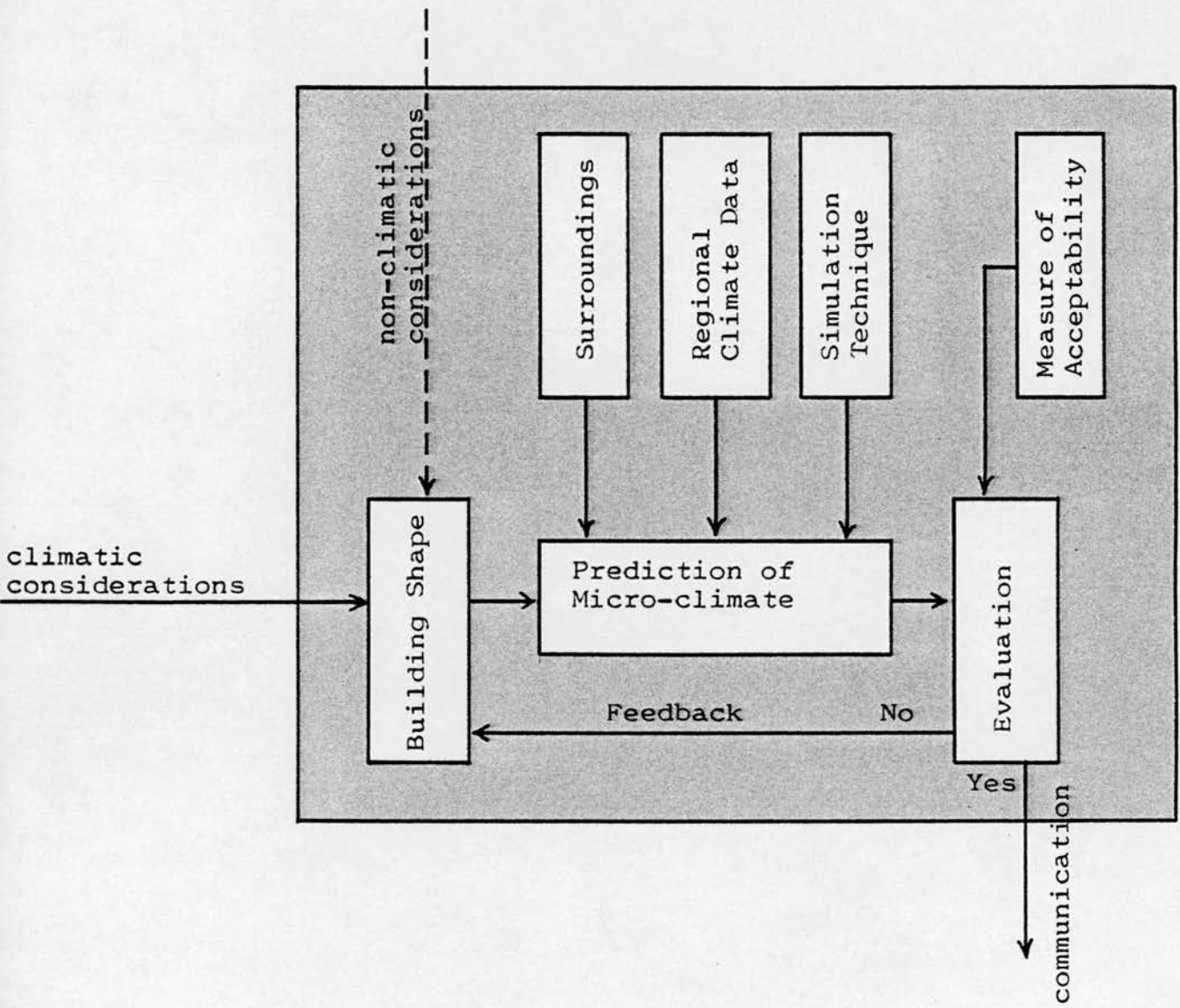


Fig. 5: The structure of the decision-making process in Stage 1 (horizontal structure)



such changes can be made easier and faster in computer-based techniques (Smith and Wilson, 1976, Hanson et al, 1982).

Stage 2, coincides with the Detail Design stage, and deals with sub-system 2:

$$(B_f + B_s)(E_{10}) = E_{1i} \quad (1.9)$$

Here, the task of the architect is to control the internal climate,  $E_{1i}$ , by means of the design of the building fabric,  $B_f$ , on the basis of knowledge of the microclimate,  $E_{10}$ , and the previously established values of shape parameters ( $B_s$ ).

At the start of Stage 2, the architect would already be equipped with data about the expected microclimate to be enveloping the building. This includes information about the characteristics of the wind-flow (wind speed, direction, pressure distribution) and the distribution of solar radiation perhaps averaged over time. He will be dealing with the choice of construction materials, the design of windows and their spatial arrangement, the design of shading devices, the availability of daylight and sunlight in the internal space, etc. Information about the shape parameters will be used to determine, for example, the rate of heat flow of the building.

The structure of the decision-making process in Stage 2 is similar in principle to that of Stage 1 (see Fig.6), but deals with sub-system 2, as mentioned. It is necessary to emphasize the feed-in of information, generated at /



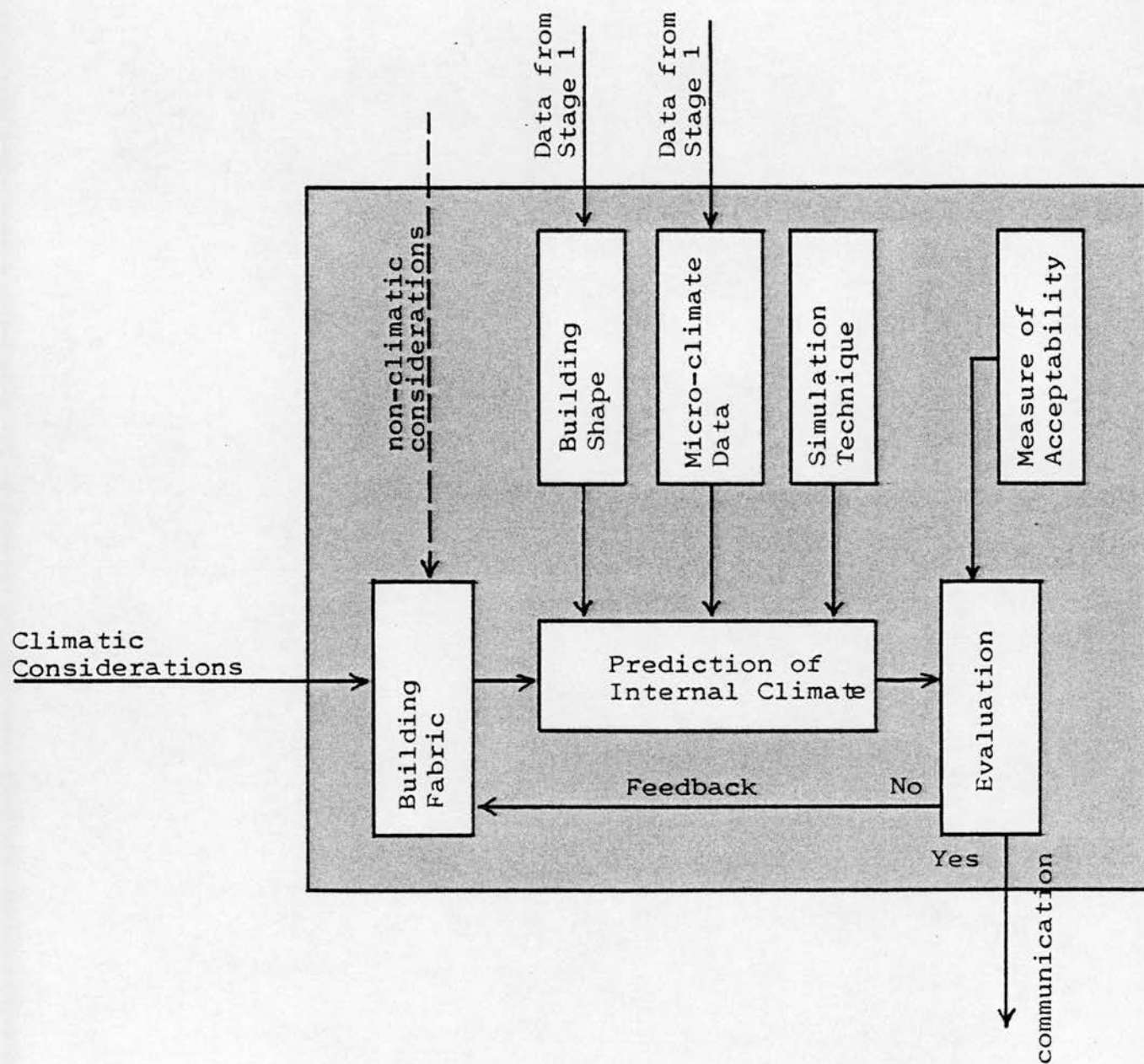


Fig. 6: The structure of the decision-making process in Stage 2 (horizontal structure)

at Stage 1 , about the microclimate and the building shape.

## 7. SUMMARY AND CONCLUSIONS

The structure of an interactive climatic design process has been introduced in this chapter, on the basis of the analysis of the building/environment System of interaction conducted in the preceding chapter.

First, a conceptual framework for the interactive approach to the planning and design of buildings was developed. In this framework, the climatic design of a building is carried out by a process of 'successive approximation' in which the final solution of the building is a modified solution, developed on the basis of knowledge of the new environment which the building itself produces. For practical reasons, it was necessary to simplify the description of building/environment System of interaction in order to simplify the prediction process of building performance during design. The assumed simplification of the System description distinguished the building shape/microclimate and the building fabric/internal climate relationships. The criteria for an acceptable microclimate indicated that an adequate microclimate for people, nearer to their needs than the regional climate, is also an advantage for the building performance in the internal climate (which is for people too).

The /

The embedding of this framework in the overall design process of the building (which was also reviewed) enabled the structure of the interactive climatic design process to be developed. This structure indicates that the interactive design process is basically a two-stage procedure: Stage 1 deals with the control of the microclimate by means of the design of the building's shape, and Stage 2 deals with the control of the internal climate by means of the design of the building's fabric and on the basis of knowledge of the microclimate.

This interactive process enables the architect to exercise adequate control of the climate of the built environment both around and inside the building. Examples of such interactive design, hidden in traditional architecture, are discussed in the following chapter.

CHAPTER VIEXAMPLES OF INTERACTIVE DESIGN  
IN TRADITIONAL ARCHITECTURE  
AND OF PARTIAL APPROACHES  
IN CONTEMPORARY ARCHITECTURECONTENTS

1. INTRODUCTION
2. THE COURTYARD HOUSE FORM
3. TRADITIONAL SETTLEMENTS
  - 3.1 Settlements in Hot-Dry Regions
  - 3.2 Settlements in Warm-Humid Regions
  - 3.3 Integration in Traditional Settlements
4. MICRO-CLIMATIC DESIGNS IN CONTEMPORARY ARCHITECTURE
  - 4.1 A Settlement in the Swedish Arctic
  - 4.2 Sea Ranch : A Coastal Development
  - 4.3 Revolutionary Ideas
5. TRADITIONAL vs. CONTEMPORARY APPROACHES
6. SUMMARY AND CONCLUSIONS

## 1. INTRODUCTION

The scope of the climatic design of buildings, as determined by the interactive approach developed in this thesis, is extended beyond the limits of the internal space to include the design of the external space as well.

In the contemporary practice of architecture and town planning the design of the external space is, generally, of a peculiarly limited kind. In discussing the "experiential reality" of the built environment, Fitch (1972, p.178) points to a "conceptual error" in modern designs, namely, the "tendency to regard outdoor spaces as purely aesthetic constructs, voids empty of microclimatic reality". Also, McHarg (1957, p.75) indicates that "the major problem of modern housing and its most conspicuous failure lies in the distribution and design of open spaces".

The conventional approach to climatic design (analysed in Ch.2) encourages this inadequacy, and contributes to it by its lack of understanding of the interdependence between the design of built forms and microclimate.

A few isolated examples of contemporary architecture have been motivated by a concern for the microclimate of the built environment, and some of these are reviewed in this chapter. However, it is building tradition and "indigenous systems" in various parts of the world which show a remarkable appreciation and understanding of the limits and potential of the interaction between built forms and /

and their microclimate.

An important feature of traditional architecture is its reliance on natural forces to condition the climate of the built environment; building traditions take advantage of simple, apparently intuitive, applications of climatic principles, through which an integration between building design and settlement planning is achieved. Of course, the use of the terms 'planning' and 'design' with reference to the production of indigenous and vernacular settlements and built forms implies a level of conscious decision-making and of preconceptions neither of which were perhaps present. However, they are useful enough when applied analytically to the product of whatever process produced these forms.

In this Chapter we illustrate, by particular examples, interactive design principles operating in the planning and design of built forms in traditional architecture. This is followed by modern examples in which the need for micro-climatic control has been appreciated.

## 2. THE COURTYARD HOUSE FORM

One of the most appropriate examples to be cited in connection with the interactive approach is the traditional courtyard house found in most of the older cities of the Middle East and North Africa, such as Baghdad, Cairo, and Marrakesh. It is a typical urban dwelling /



dwelling in these cities; an inward-looking, two-storey house, of massive structure, with a flat roof and a small number of openings. The internal spaces adjoin a central court open to the sky, (see Fig.1).

The historical persistence of the courtyard house ("also known as the Roman atrium and the Spanish patio house" (Dunham, 1960, p.663) ) is indicative of its social and environmental advantages.<sup>1</sup> An intrinsic attribute of this built form is "the intimate relationship [it establishes] between the external and internal space" (McHarg, 1957, p.75). A major contributor to this relationship is the micro-climatic behaviour of the court,<sup>2</sup>(see Fig.2).

The exclusion of heat from buildings in hot-dry regions is a major problem facing design. The form of traditional courtyard houses embodies a combination of geometry and fabric which effectively offsets the heat impact of the hot dry climates where such houses are usually found.

The height of the courtyard is normally greater than any /

- 
1. See Schoenaure, 1981, for a historical review on the evolution of courtyard houses in Mesopotamia, Egypt, Indus and India, China, and Greece.
  2. See Mohsen, 1978, for a detailed study of the thermal behaviour of courtyard houses.



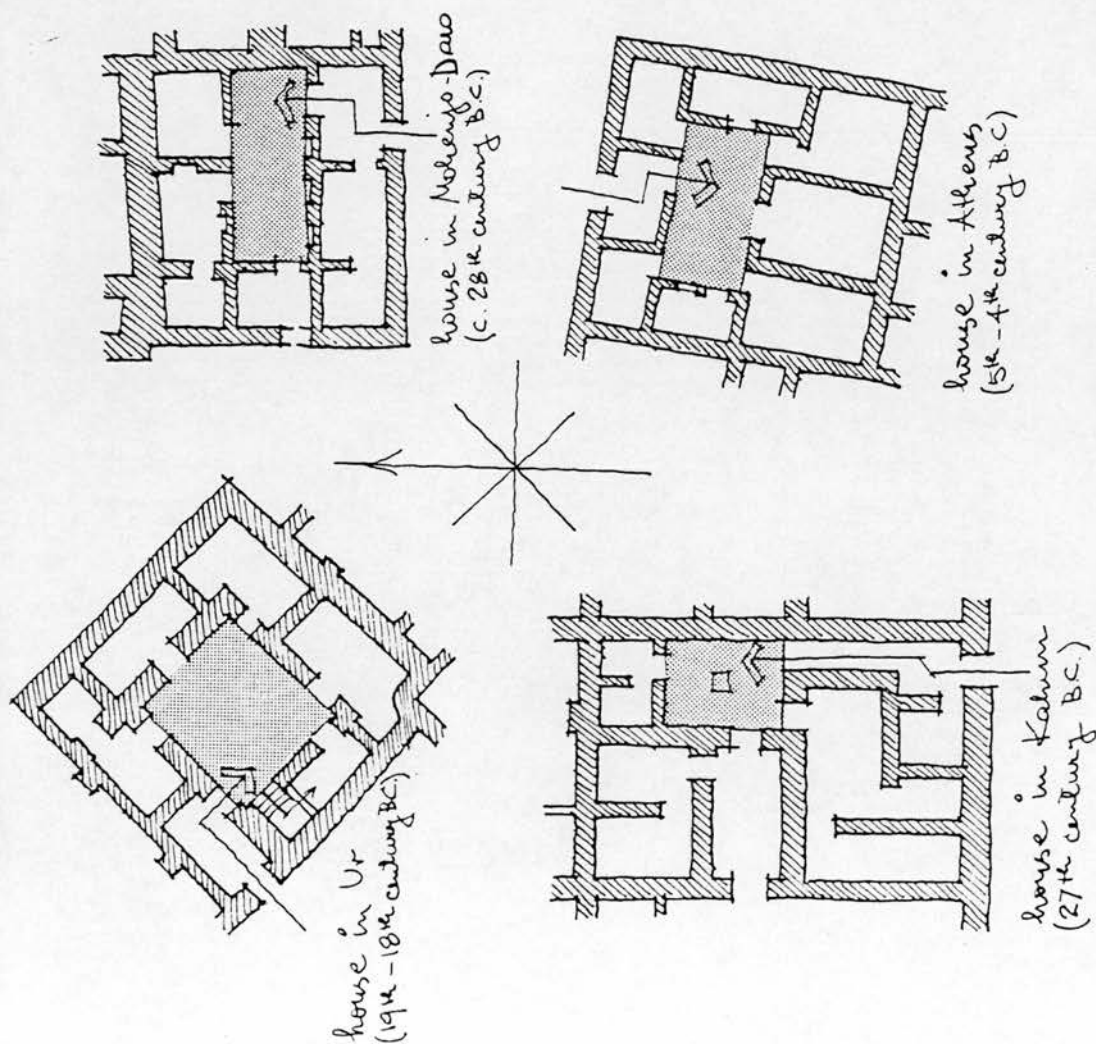
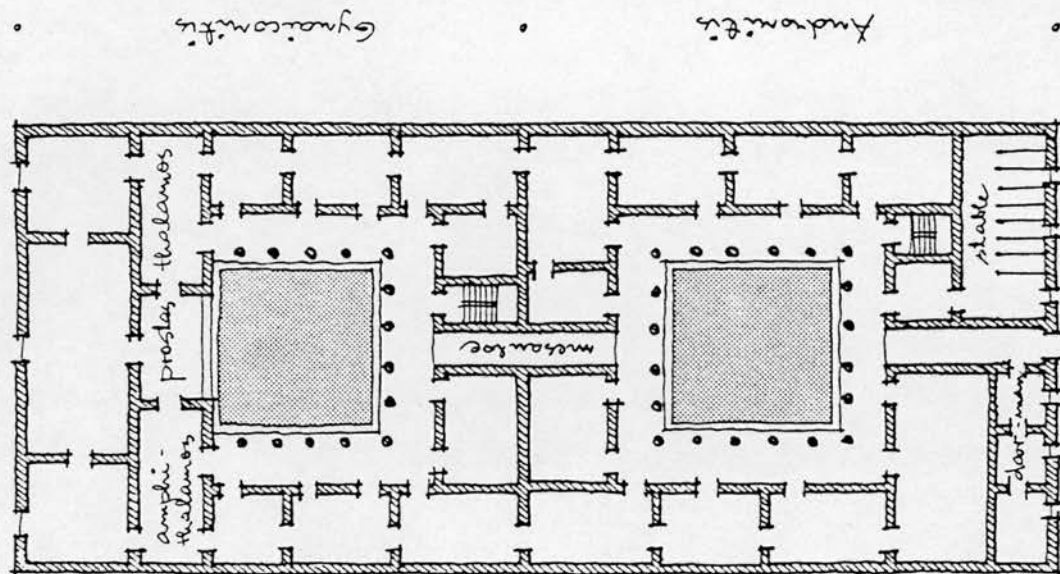


Fig. 1: Examples of Traditional Courtyard Houses,  
(from: Schoenauer, 1981, p. xxii and p. 210)



Plan of Vitruvius' Greek House  
according to Becker

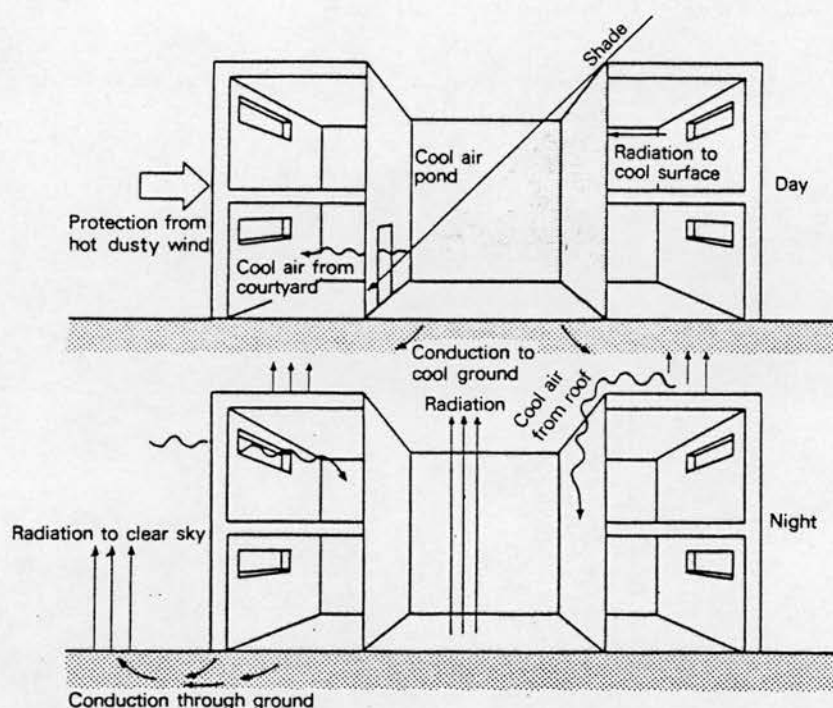


Fig.2: The thermal system of a two-storey courtyard house (from: Koenigsberger et. al, 1974, p. 206)

any of its plan dimensions (Al-Azzawi, 1969, p.92). Galleries and covered terraces occupy one or more of the court's sides. Such geometry produces a cool and shady microclimate which serves a double function: it suits people's social activities in the court and, at the same time it reduces the irradiation load falling on the inner surfaces of the court. This reduction of the irradiation load advantageously affects the internal climate - an advantage augmented by the use of massive structure /

structure and small openings. The principles of interactive design (previously discussed in the preceding chapter) are particularly clearly evident; the geometry ensures a favourable microclimate, and the fabric design utilizes this microclimate to produce a favourable internal climate.

The microclimate of the court is also free of the hot and dusty winds, such as the Khamasin in Egypt, which can be an inhospitable and unhealthy feature of hot-dry regions. The evaporative cooling effect of plants and water fountains which normally furnish the court enhance the court's improvement of its microclimate.

Although the courtyard house as a traditional built form was developed, mainly, in hot-dry regions, its advantageous behaviour characteristics with respect to 'micro-wind' protection are a major factor behind its modern application in cold climates<sup>1</sup>. In a court that is designed to capture (instead of excluding) solar radiation, protection from the wind can produce a sunny microclimate, attractive for outdoor activities, and at the same time reduce air-infiltration into the internal space, thus reducing in turn wind-mediated heat loss from the building.

It /

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1. On the modern application of courtyard houses, see for example, McHarg, 1957; Macintosh, 1973.

It is difficult to isolate these environmental gains from the psycho-social advantages of a courtyard house. The dwelling which offers habitable internal and external spaces offers more than an environmental gain. The native languages of some of the traditional builders of courtyard houses give a clear indication of this.

The Chinese word for 'courtyard', 天井, which is translated as "the well of heaven" (Schoenaure, 1981, p.252)<sup>1</sup> carries a strong sense of the admirable qualities which this form attaches to a built environment. The words Sakan and Maskan are the Arabic words for house. Sakinah means peace of mind; tranquility, calm, peace. Ismail (cited by Schoenaure, 1981, p.36) remarks that "the inward-looking Sakan, open to the calm of the sky, made cool by the element of water, self-contained and peaceful, the deliberate antithesis of the harsh public world..., is the place where the early Arab family found their Sakina[h]".

The fact that such words carry deep psychological meanings is indicative of a cultural attitude in which the concepts of building and dwelling are hardly separable. It is a characteristic of traditional, pre-technological societies that the attitudes implicit in these words are shared /

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1. The author acknowledges the assistance of Chan, Shieh-Haw for the Chinese characters cited here, which are not included in Schoenaure, *ibid.*

shared by the local builder and the dweller. The traditional built forms (and settlement structures) of such societies are the repositories of an implicit knowledge of the relationship between dwelling, and the pragmatic approach to building. Such an approach embodies, among other things, a successful exploitation of form/microclimate interaction.

### 3. TRADITIONAL SETTLEMENTS

Looking beyond the form of individual buildings, the planning of many traditional settlements provides other examples of the successful exploitation of the interaction between built forms and their microclimates. The way in which buildings are grouped takes into consideration the resultant microclimate in relation to the inhabitants' needs. The compactness of traditional settlements in hot-dry regions and the loose, spread-out layout of settlements in warm-humid regions are two contrasting responses to this principle.

#### 3.1 Settlements in Hot-Dry Regions

In hot-dry regions the compact grouping of buildings is a protection against the sun's heat. For example, in Marrakesh (see Fig.3) the compactness of the buildings protects both people in the street, or public space, and the external surfaces of the buildings themselves from intense /



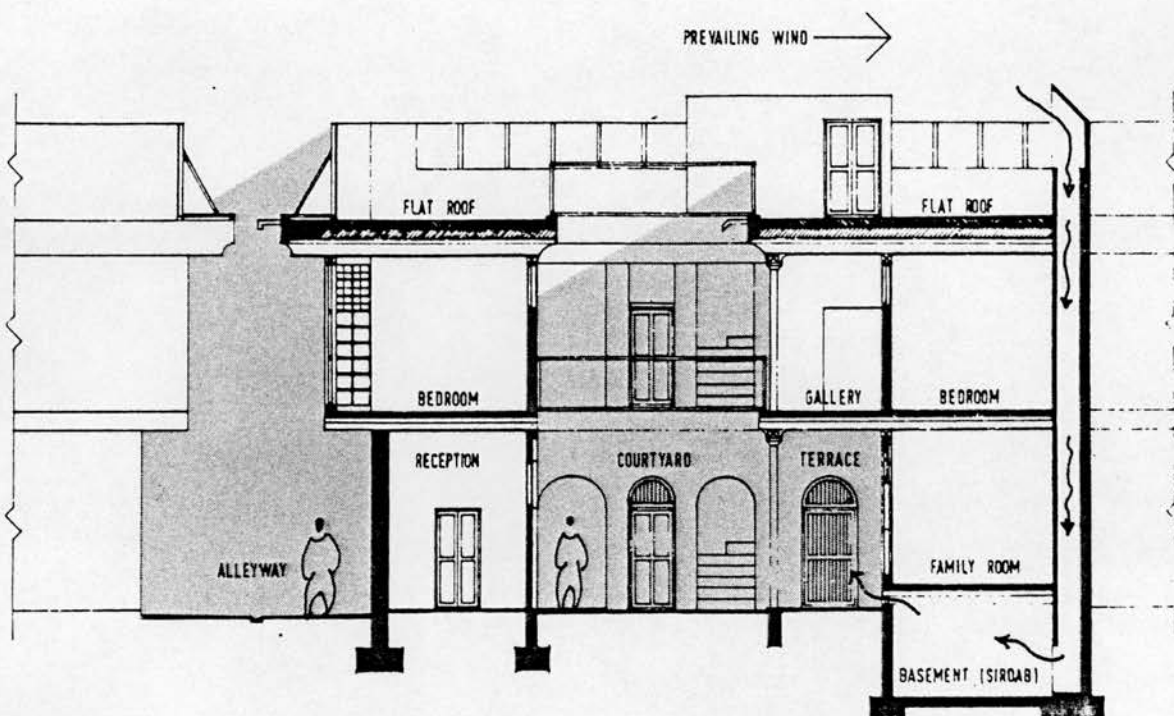


Fig. 4: Section of a typical courtyard house in Baghdad (from: Al-Azzawi, 1969, p. 95)



Fig. 3: 'Marrakesh' from the air, (from: Saini, 1973, p. 84)



Fig. 5: A typical winding street in Jaisalmer, India (from: Saini, 1973, p. 86)

intense solar radiation. Courtyard built forms, which are adapted for public institutions as well as housing, are closely grouped, resulting in narrow alleyways, shaded for most of the day, (see Figs. 4 and 5).

The microclimate of such alleyways is similar to that of the courtyards. As Fathy (cited by Evans, 1980, p.154) indicates, "....a narrow, winding street with a closed vista has the same function as the courtyard in a house: to regular temperature...". The alleyways are proportioned to the height of the enclosing buildings and result in hierarchical order in the street network which maintains a favourable microclimate at a large scale of the settlement.

In the south-west United States, the typical house form of the Pueblo is the adobe house: a mud masonry cuboid form with a small number of openings located in its south-facing wall, (see Fig.6). The mud structure is an advantage in this hot-dry region because of its combination of high thermal capacity and high insulation which offset diurnal temperature variations. Unlike the courtyard house, however, this cuboid form has no distinct external space with advantageous microclimate of its own. Instead, it is used as the basic unit of a larger form composed of multiple dwellings and having a distinctive microclimate.

The houses are grouped in mass formation, (see Fig.7) carefully oriented and extremely compact, with covered passageways penetrating them. The form of the cluster as  
a /



Fig. 9: Cliff dwelling in Mesa Verda  
(from: Scully, 1975, p. 30)

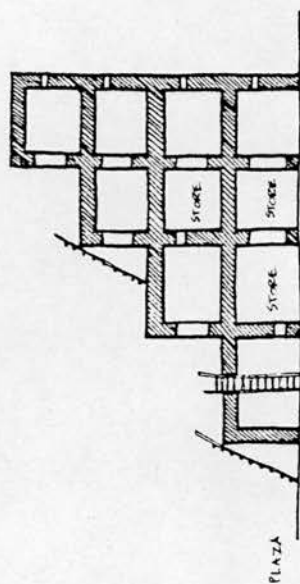
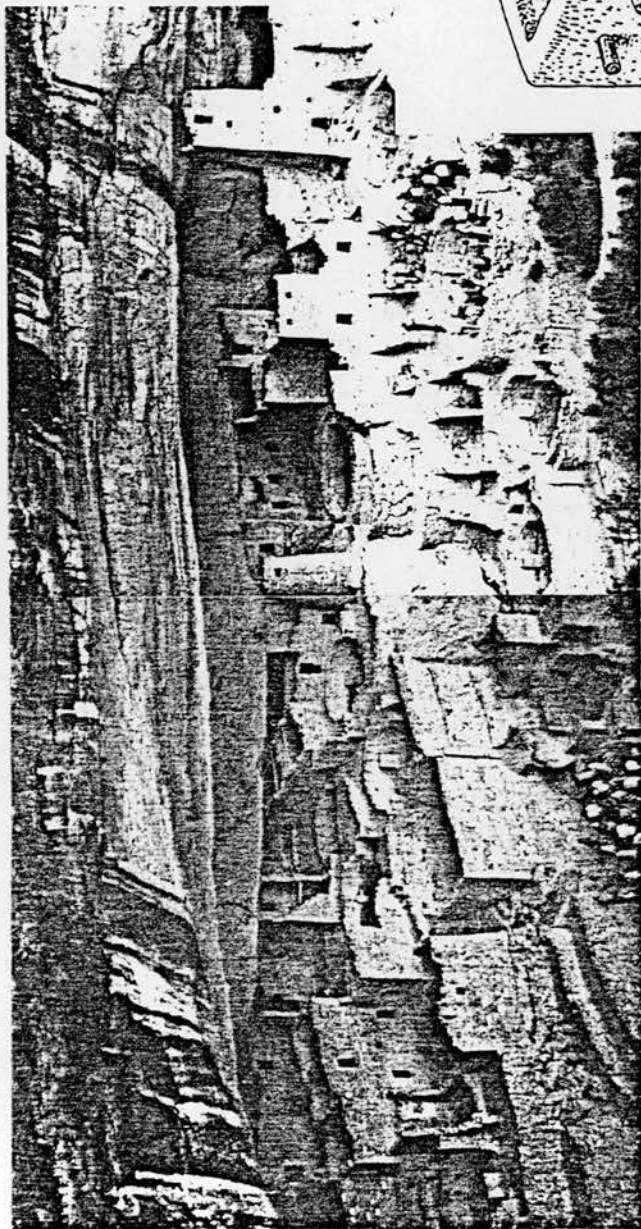


Fig. 8: A "tiered" section  
(from: Rapoport, 1969 b,  
p. 69)

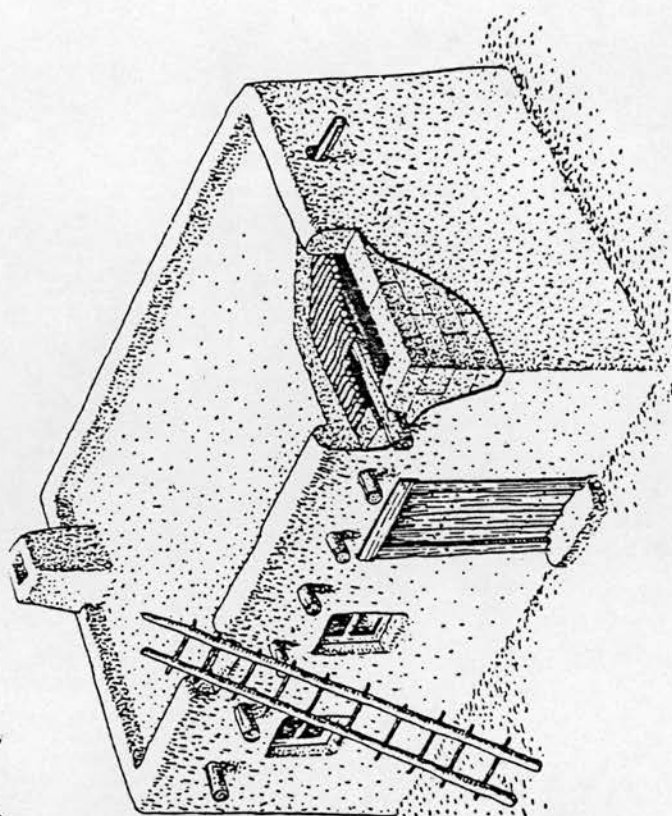


Fig. 6: The "adobe" house, a typical  
Pueblo house (from: Fitch, 1972,  
p. 267)

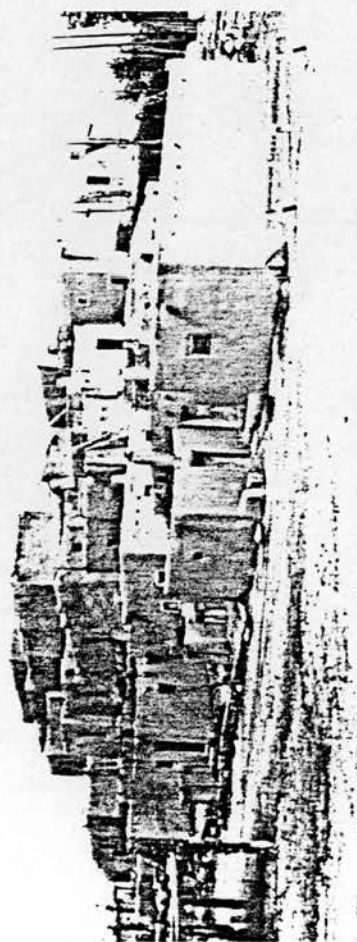


Fig. 7: A Pueblo village in Taos,  
(from: Scully, 1975, p. 80)

a whole - "the Great House" (Scully, 1975, p.14) varies from one village to another; however, it is always designed in a tiered section with its terraces facing south, (see Fig.8). The overall heat exchange of a house unit in the Great House is greatly influenced by the compactness of the cluster. The mutual shading of surfaces reduces solar radiation falling on the exposed walls. East and West walls are kept to a minimum. Fitch (1972, p.271) indicates that, the exterior walls per unit are reduced by some 60 per cent.

In the cliff dwellings of Mesa Verda, the microclimate of the Great House is further improved as a result of a favourable site climate, (see Fig.9). Here, the pueblo exploited the dynamics of the sun's penetration at the bottom /

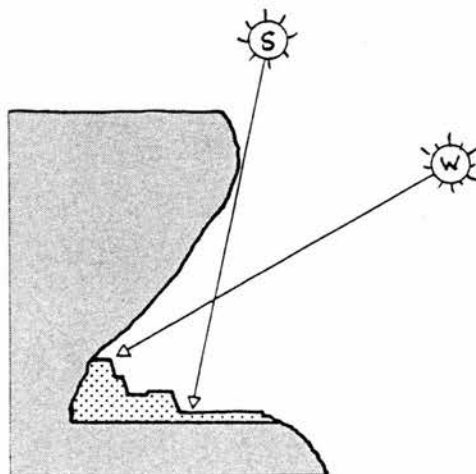


Fig. 9a: Seasonal difference in insolation in longhouse pueblo, Mesa Verda (adapted from: Knowles, 1974,p.24)

bottom of a cliff by locating the whole settlement inside a south-facing cave. The whole settlement benefits from the winter sun which penetrates deeply inside the cave, and in summer it is protected from the sun by shadows cast from the upper edge of the cave, (Knowles, 1974).

### 3.2 Settlements in Warm-Humid Regions

A compact settlement in a warm-humid climate, would be a major disadvantage to its inhabitants. Wind-induced heat loss from the human body is a major source of relief from the heat in this climate. Free-passage of air movement as well as shading are the two basic requirements which the planning and design of buildings must achieve. Grouping the buildings close together would give desirable protection against solar radiation, but would also obstruct the air movement. It would also tend to store the day's heat on into the night, which is not at all desirable in climates where there is little diurnal variation in air temperature, as is the case in warm-humid climates.

The traditional settlements around the Equator, such as in Malaysia, Indonesia and the Gold Coast of Africa (Ghana), are normally low density villages (Fry and Drew, 1956). Buildings are loosely grouped, (see Fig.10) so as to encourage maximum air movement around and within the group, and in the same way individual buildings are designed with large overhangs and embedded in the shade of surrounding trees.

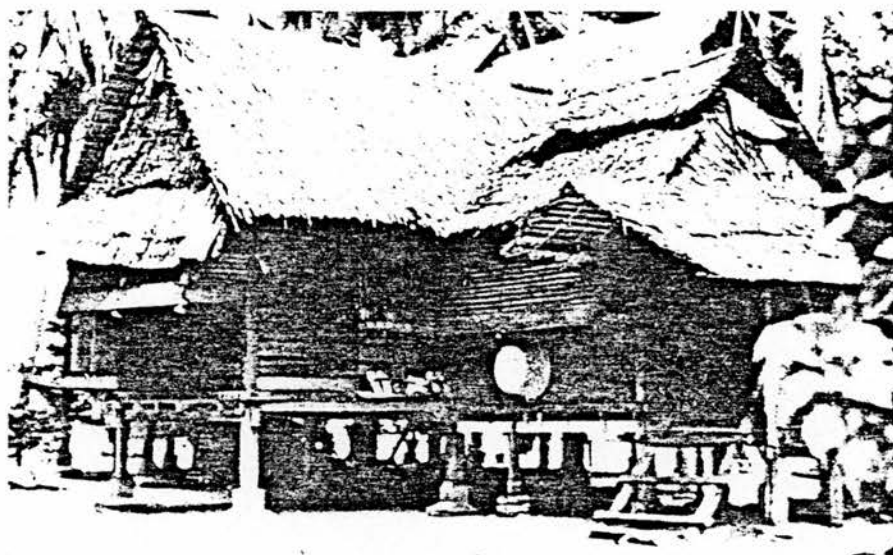


Fig. 11: A traditional Malay timber house,  
(from: Markus and Morris, 1980, p. 160)

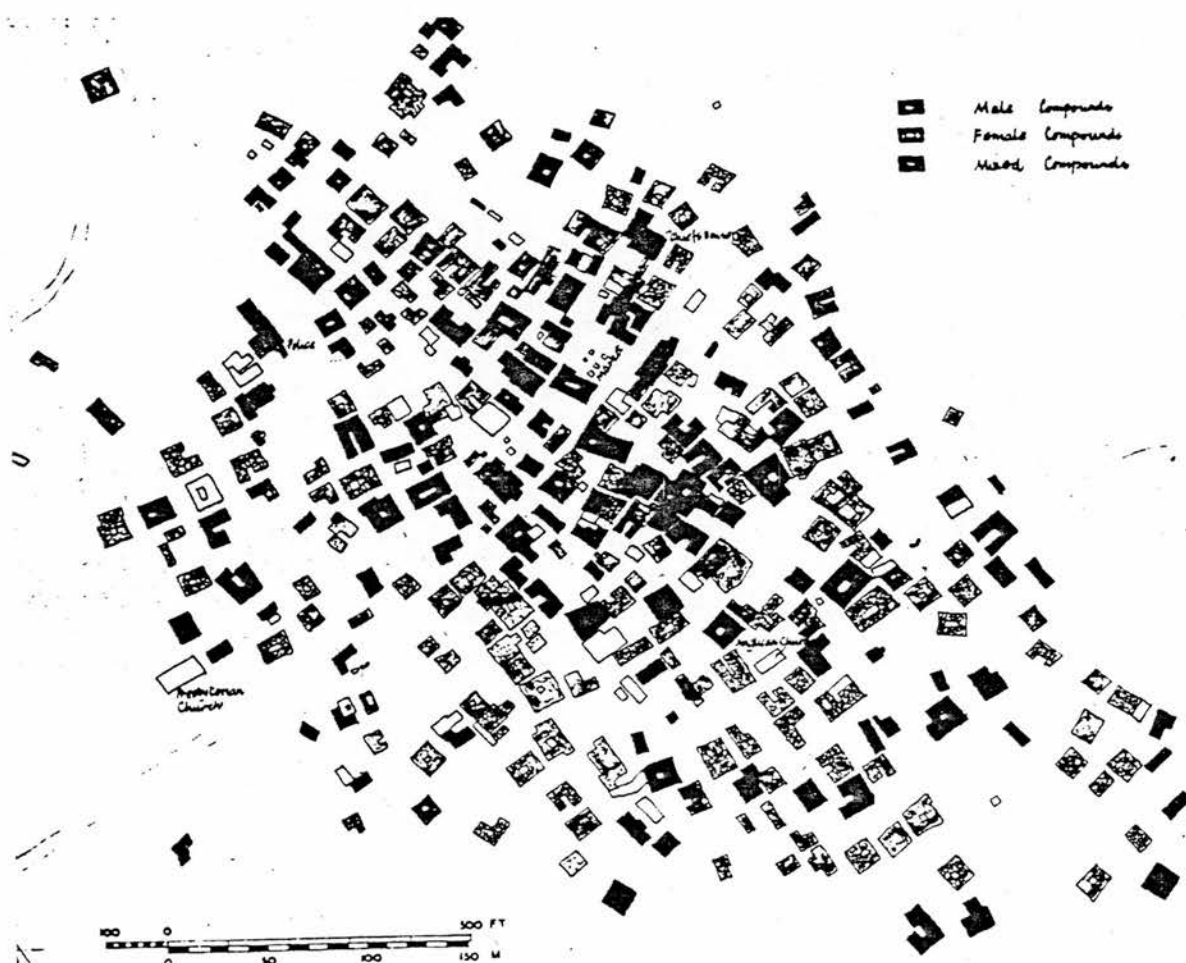


Fig. 10: A plan of a village in Tema, Gold Coast,  
(from: Fry and Drew, 1956, p. 144)



The traditional "Malay timber house" (see Fig.11) is a typical house form in warm-humid regions, (Markus and Morris, 1980, p.160). The house is raised on stilts and has a lightweight structure, with a large gable roof and large openings. The roof throws a wide area of shadow over the dwelling while the low-density grouping of buildings together with the large openings make possible adequate natural ventilation of the internal space.

### 3.3 Integration in Traditional Settlements

What these examples of traditional settlements have in common is fundamental to any attempt to control the climate of the built environment, namely: the principles which underly the climatic adaptation of individual buildings are echoed in the layout of the whole settlement.

When air movement is required for human satisfaction it is encouraged around the building by a minimum obstruction of neighbouring buildings as it is allowed inside the building by the provision of large openings. Or, when insulation is a problem of discomfort, a compact grouping is applied which protects both people and buildings, and massive walls with smaller openings are erected to protect the internal climate.

Commenting on a compact, "closed-in" settlement composed of courtyard built forms, Egli (1951, p.79) emphasizes that "the attitude of the whole settlement repeats /

repeats the attitude maintained by each part". This inevitably produces a stable system in which the whole performs climatically in much the same way as its parts. The climatic performance of an individual building has not been offset by neighbouring buildings; on the contrary, it is enhanced by an advantageous microclimate which is produced by a group of buildings working together.

In some cases, (as in hot-dry regions) the interaction of buildings is a protection by intervention i.e. to obscure solar radiation and give shelter from dusty winds. In other cases, (warm-humid regions) it is less intervening in the sense that it would allow the natural phenomena to prevail without disruption, i.e. allowing free-passage of air movement between the buildings.

In both cases of interaction, however, the desires and needs of the inhabitants of such a stable system are met inside the building as they are outside it. The result is the maximum satisfaction of such needs. It is only when the sphere of influence of the climatic adaptation of buildings is extended, as it is in traditional architecture, to include the control of the microclimate of external spaces that such satisfaction is possible.

The few examples of traditional architecture and settlements which have been given could be multiplied many times over, but the purpose of giving them was to illustrate a principal rather than to provide a detailed study. The organic /



organic unity of the traditional settlement, which is clearly evident in the integration between the climatic adaptation of the buildings and the settlement's spatial structure, is certainly remarkably successful, and we should seek to re-establish it in contemporary practice.

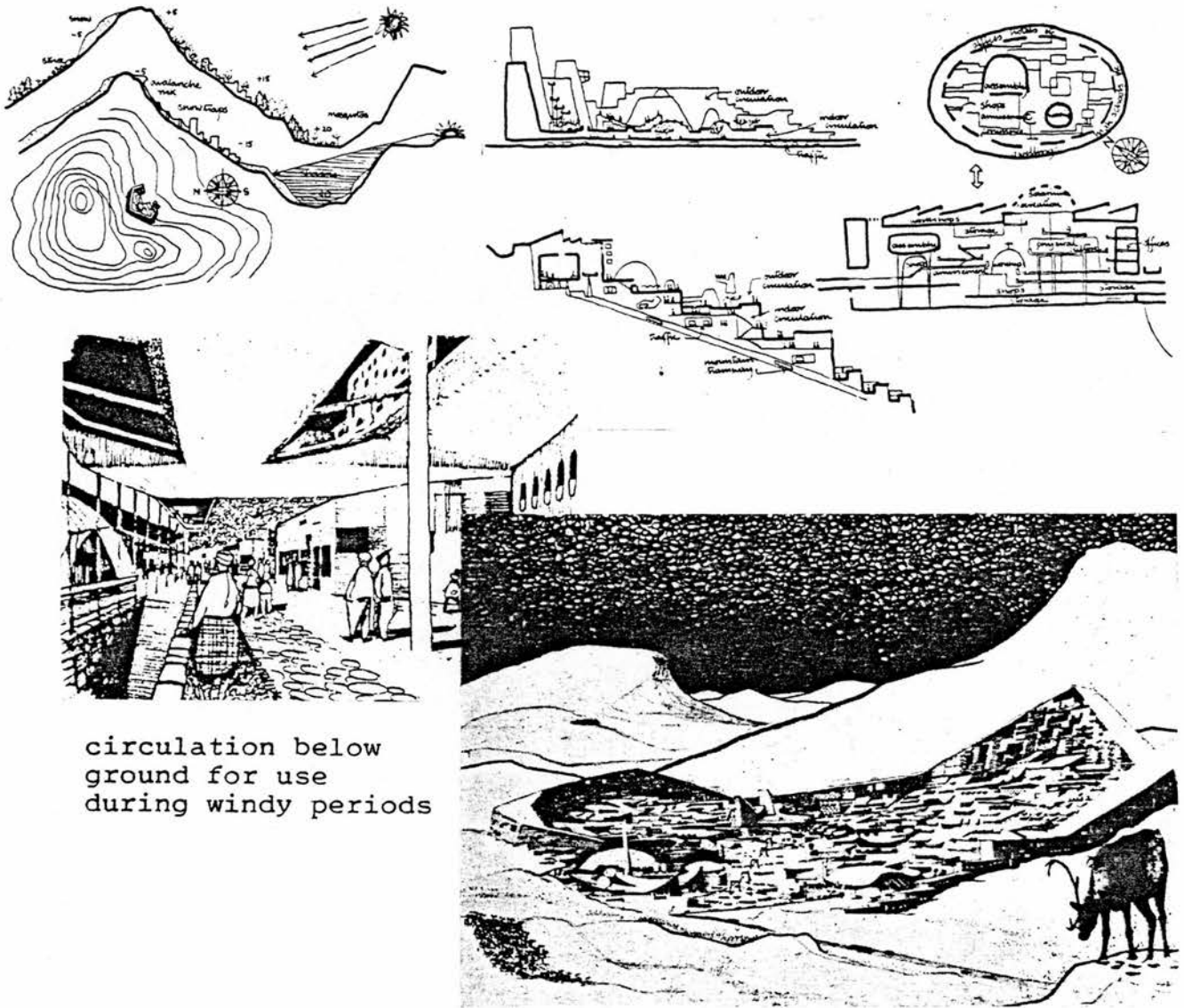
#### 4. MICRO-CLIMATIC DESIGNS IN CONTEMPORARY ARCHITECTURE

Unlike in traditional architecture, environmental manipulation in contemporary architecture is almost entirely limited to the design of buildings to control the internal climate. A few examples exist which are exceptions to this, in the sense that they consciously pursue micro-climatic design, and employ various techniques for improving the microclimate of the built environment.

##### 4.1 A Settlement in the Swedish Arctic

Ralph Erskine's (1960) theoretical study of a settlement in the Swedish Arctic (see Fig.12), which provided the basis for two housing schemes at Kiruna and Svappavaara (see Fig.13), is a good example of micro-climatic design.

The long, dark and severe winter of the Arctic causes not only physical discomfort but also psychological problems of isolation and poverty of stimuli (Zrudlo, 1971). Erskine's proposals attempt to overcome both classes of problem by extending the influence of the climatic design to include the external spaces. Protection from wind and exposure to solar radiation are basic requirements for human satisfaction in /



circulation below  
ground for use  
during windy periods

Fig. 12: Ralph Erskine's study of a settlement in the Swedish Arctic (from: Erskine, 1960)

in the Arctic. Erskine (as cited by Egelius, 1977, p. 785) remarks that:

"Here, houses and towns should open like flowers to the sun of spring and summer but also like flowers, turn their backs on /



Fig. 13: A proposed new town in Svappavaara  
(from Egelius 1977, p. 790)

on the shadows and the cold northern winds, offering sun-warmth and wind protection to their terraces, gardens and streets".

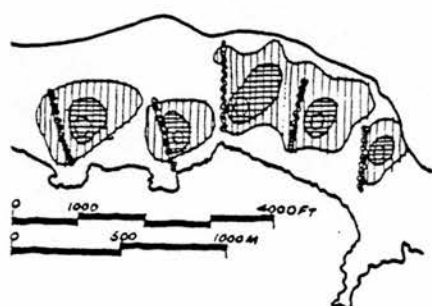
Several planning measures were taken by Erskine to improve the local climate of the settlement as a whole. A prime measure in his proposals is that housing was arranged in a wall-like formation, enclosing the settlement against snowdrifting and acting as a windbreak to protect it /

it from the persistent northern winds.

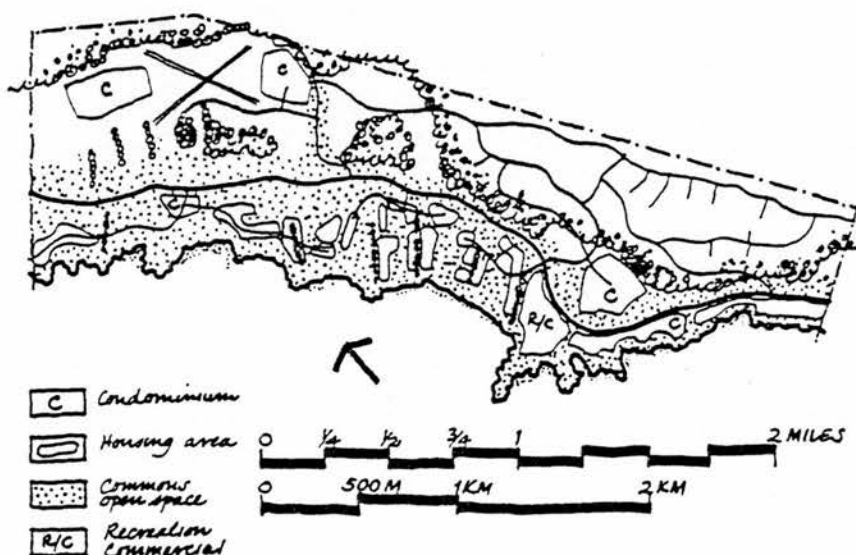
In addition, a south-facing slope, which captures the low winter sun, was chosen as the site. The tallest buildings are located high up the slope to avoid shadowing smaller ones. The circulation pattern provides two micro-climates: Above the ground for use during sunny periods, and below the ground for windy periods.

#### 4.2 Sea Ranch: A Coastal Development

Sea Ranch is a second-home community developed on the northern Californian coast by Oceanic Properties (Sharp, 1972, p.278). Lawrence Halprin and Associates prepared the/



(14a)



(14b)

Fig. 14: 14a, analysis of local wind,  
14b, proposed land-use plan  
(from: Laurie, 1976, p.108,p.109)

the planning guidelines for land uses and buildings form (Laurie, 1976, pp.107-110, Fitch, 1972, pp.282-4). Although the program called for an economic use of the land, a major objective was to maintain the visual and ecological qualities of the existing landscape. A controlled growth was therefore required, and the studies of the local climate in particular had major impacts on the planning and design of the built forms.

The site analysis, which gave prime consideration to local wind conditions (see Fig.14), enabled Halprin to identify suitable locations for condominiums, single-family houses, and community facilities. The wind-shaped profile of native trees inspired the design of the mono-pitched roofs of buildings, (see Fig.15).

In planning the layout of the single-family houses "it was proposed that houses be oriented toward north, with outdoor areas and parking spaces situated on the leeward side of the building" where the shelter effect is increased by the mono-pitched roofs (Laurie, 1976, p.108). In Charles Moore's design of the condominium, various dwellings jointed together into a larger structure, enclosing open spaces with wind-free microclimates. The arrangement of the athletic fields incorporated protective land forms in order to improve their micro-wind.



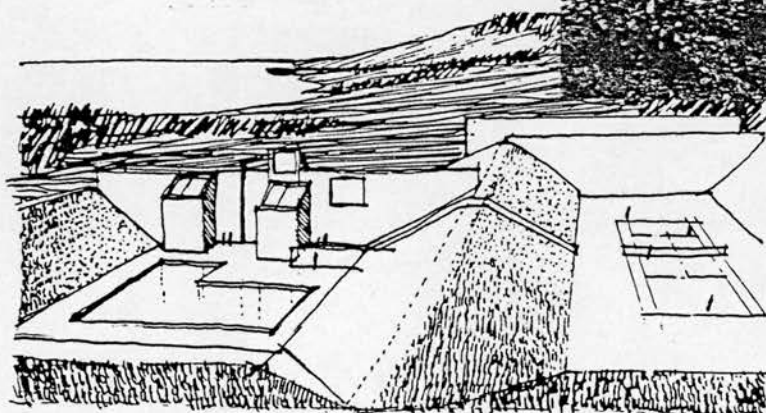
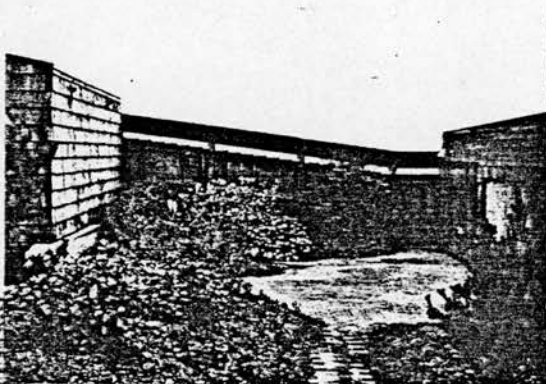
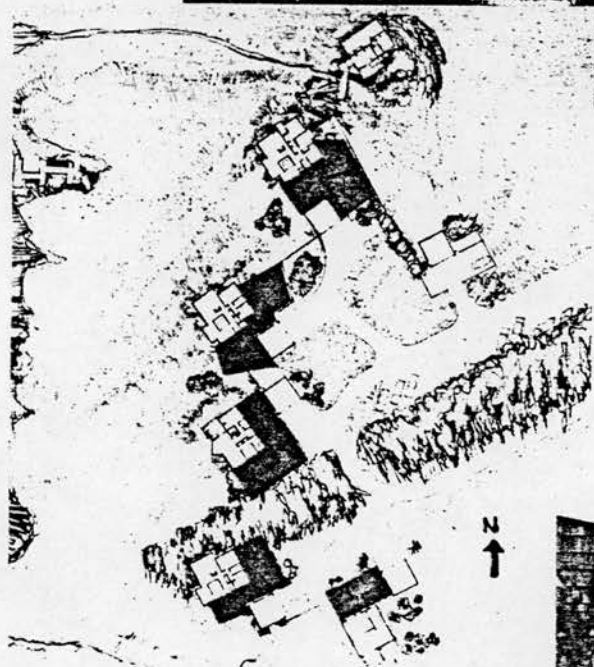


15a: (from: Fitch, 1972, p.283-4)

above: mono-pitched roofs inspired by native trees

left: open spaces are in the leeward side of single houses

below: protected garden from wind



15b:

above: protective land forms (from: Laurie, 1976, p.110)

right: a view of courtyard in the condominium (from: Sharp, 1972, p.279)

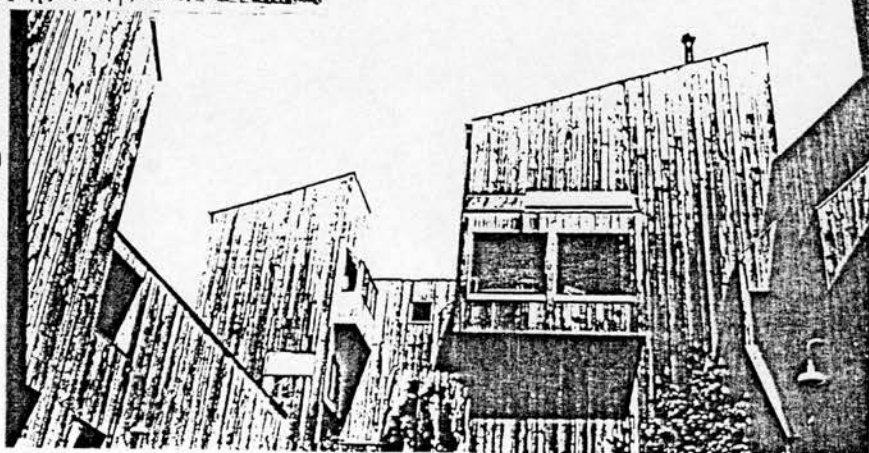


Fig. 15: Examples of the coastal development at Sea Ranch



#### 4.3 Revolutionary Ideas

Other examples have considered radial design concepts in their search for a means of controlling the microclimate of built forms.

Buckminster Fuller's proposed two-mile diameter dome over New York city (see Fig. 16) is a well-known example. His ideas for large scale protective structures are clearly motivated by a concern for a climatically unrestrained way of life, including the 'out-of-doors'. He describes the U.S. Pavilion, Expo 67, Montreal (see Fig. 17) as "an environmental valve...space for whole communities to live in a benign physical microcosm" (cited by Sharp, 1972, p.281).

This concept has been considered in large- and small-scale development proposals. An international team led by Frei Otto proposed to house an entire city (15,000 to 45,000 population) in the Arctic under an inflated dome (see Fig.18) covering an area of  $3 \text{ Km}^2$  (Hix, 1974, p.193). A group of M.I.T. graduate students proposed to incorporate a transparent dome in the design of a house (Hix, 1974, p. 169) (see Fig.19).

These solutions are proposed for cold climates, and the environmental advantages of a transparent dome in this case are clear: trapping the sun's heat and keeping away precipitation, wind, etc. This may be attractive enough for some; Hix (1974, p.169) regards such proposals as representing a "mini-Garden-of-Eden attitude". However, it /

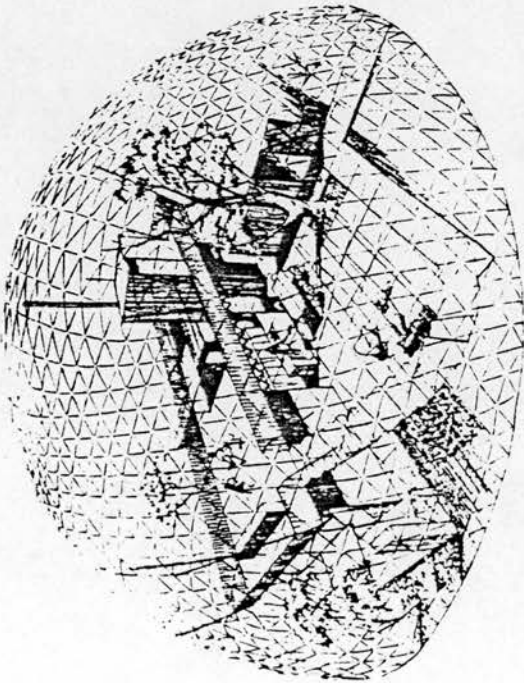


Fig. 19: "The Industrial House"  
(from: Hix, 1974, p.170)

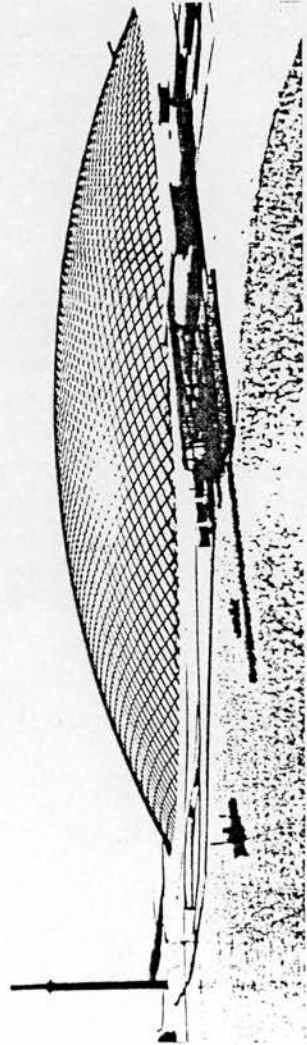


Fig. 18: "Arctic City",  
(from: Hix, 1974, p. 195)

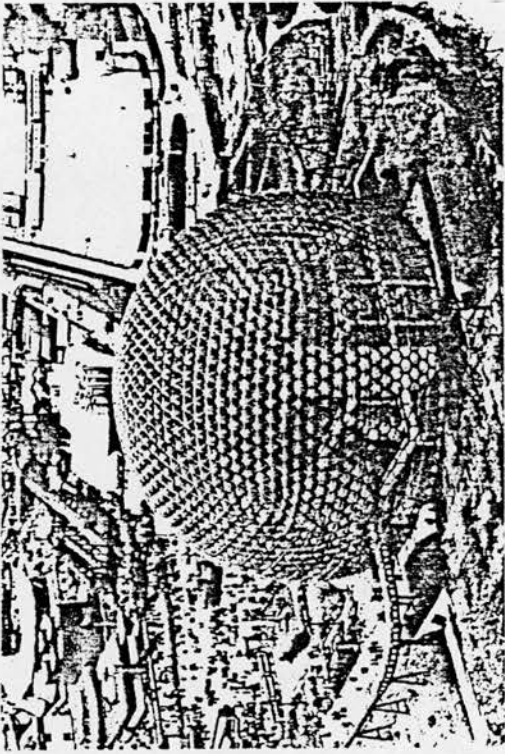


Fig. 17: The U.S. Pavilion, Expo 67,  
Montreal (from: Sharp, 1972,  
p. 280)



Fig. 16: Fuller's proposed dome over  
New York City  
(from: Hix, 1974, p. 184)

it can be deceptive - aside from the technical problems which could arise from living permanently under a 'roof' and for which there is no empirical information to judge the results. Besides, a transparent dome is no 'panacea' for the environmental problems. It resolves some, as mentioned; but it generates others such as the accumulation of air pollution or the problems of air change.

Meanwhile, other proposals are equally motivated by a concern for tempering the microclimate of outdoor spaces between buildings. Etkin and Goering (1971, p.541) have stated that "the forms generated by conventional structures as we know them [and as the conventional approach to climatic design encourages us to adapt them, piecemeally,] largely exclude the external environment". These authors considered using an air-curtain as a structural envelope to produce so-called "dynamic" structures; rapidly moving "jet sheets" of air which could spread horizontally as a roof (see fig.20) or in an annular wall/roof configuration (see Fig.21), protecting thus an articulated space from wind, dust, precipitation, etc.

The significance of these somewhat ambitious proposals lies not in the proposed solutions, but rather in the motivation behind them. Etkin and Goering's own remarks (1971, p.543) are:

"The operative principle is to extend our lives to include more 'outdoor' space under conditions of increased comfort - to reduce the difference between 'outdoor and 'indoor' while retaining protection against the inclement aspects of 'out of door'."  
(my emphasis)

Nevertheless, /

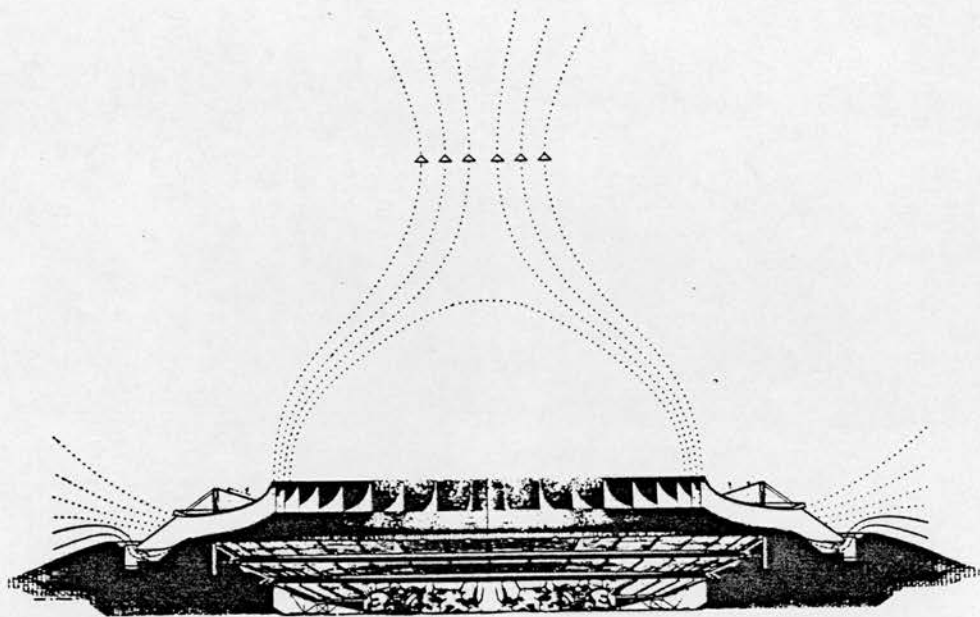


Fig. 21: A hypothetical stadium under  
an annual air-curtain  
(from: Goering, 1973, p.11)

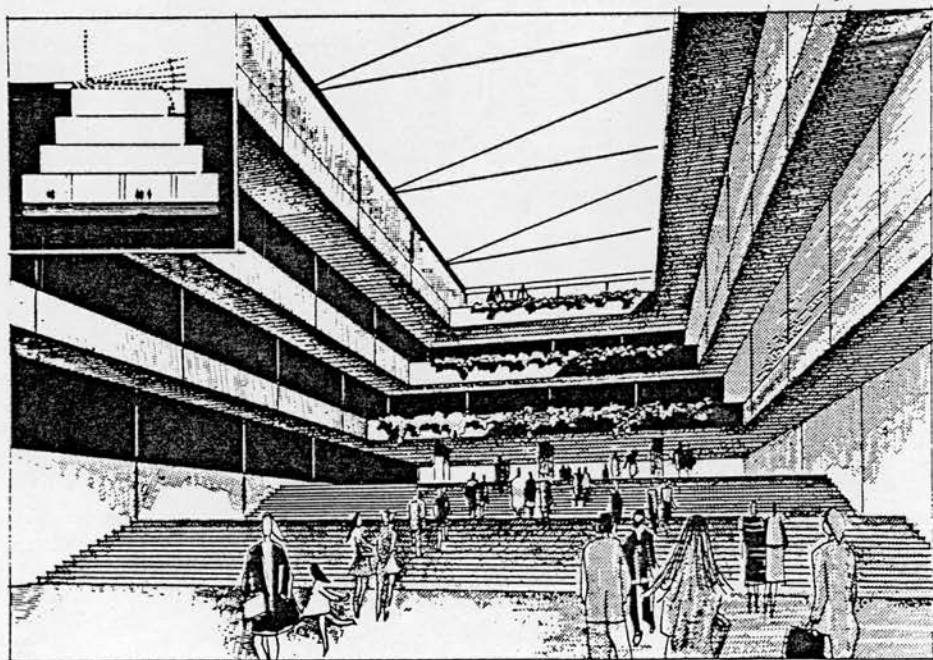


Fig. 20: A hypothetical street or court  
protected by an air-curtain  
(from: Goering, 1973, p.11)



Nevertheless, these 'revolutionary ideas' remain as they are - revolutionary. We need not go to such extremes as 'domes' and 'jet sheets of air' in order to control the microclimate in settlements. All that is required is a better understanding and appreciation of the built form/microclimate interaction, so that the microclimate can be deliberately controlled, through efficient and economic procedures for both the design of individual buildings and the planning of settlements.

#### 5. TRADITIONAL vs CONTEMPORARY APPROACHES

A basic difference of methodology, relating to micro-climatic controls, exists between these contemporary designs and the traditional solutions discussed earlier (sections 2 and 3).

The contemporary approach seeks to improve the micro-climate of built forms by grossly improving the local climate of the whole settlement. The means of producing such gross improvement vary from 'site selection' to 'wall-like' formation of buildings, or the controversial 'dome'. These can be seen as measures which have a wide-spread effect on the local climate, representing (with the exception perhaps of 'domes') concepts worthy of pursuing, though insufficient for establishing adequate control of the microclimate around buildings.

The /

The methodology of this contemporary approach is based on a 'linear' strategy, in which some elements improve the environment to the benefit of others. Commenting on large-scale protective techniques and the benefits of their improved environments, Fitch (1972, p.276) indicates that:

"Within this context of ameliorated conditions, individual buildings of more normal design could provide the more precise environmental control required".

Although an 'ameliorated' local climate enhances the microclimate of a building, and therefore makes a normal design more efficient, it should not be taken as a substitute for a 'good' microclimate as achieved by an advantageous building/microclimate relationship. The attempt to improve the building's microclimate through gross improvement of the local climate does not eliminate the possibility of diminishing any possible gain, by factors originating in the immediate vicinity of the building (including the building itself), which directly affect the building's microclimate - especially the micro-wind and micro-sun conditions.

The organic structure of traditional settlements leads also to ameliorated local conditions (with the benefit mentioned above) but through a more comprehensive strategy.

The spatial structure of the settlement echoes the climatic principles adapted in the design of individual buildings. Each building is active in the amelioration process of the local climate, by being part of a whole (the settlement)/



settlement) which works in much the same way as its parts. In this case, the local climate is the result of the cumulative effect of small-scale micro-climatic improvements. These improvements are the outcome of the interaction between each building and its microclimate as 'sub-systems'. As a whole, the settlement interacts with its local climate (the 'System'). There is no conflict, but rather harmony between the 'System' and its sub-systems.

The advantage of this organic unity of traditional settlements is that it eliminates the possible diminishing of gains from improved local climate, beside being less prone to significant perturbation as individual parts of the settlement are changed with time. It also relies on socially and economically acceptable means of design which represent a synthesis of physical and other human requirements.

## 6. SUMMARY AND CONCLUSIONS

Traditional built forms and settlement structures of pre-technological societies are the repositories of an implicit knowledge of the relationship between dwelling, and the pragmatic approach to building. The analysis of some examples of traditional forms, conducted in this chapter, showed the similarities between the principles of the interactive approach to climatic design which was developed in the last two chapters and those implicit in building traditions.

A few examples of contemporary designs which appreciate the value of 'good' microclimate were also reviewed.

The difference of methodology between the traditional and contemporary approaches has been discussed. The contemporary approach relies on gross improvements of the local climate whereby to improve the microclimate around buildings. It was argued that this is an inadequate strategy for micro-climatic control. The organic structure of traditional settlements offered a more comprehensive strategy because it deals, basically, and directly, with the building/environment interaction in synthesis with other requirements.

PART IIIAPPRAISAL OF THE INTERACTIVE  
APPROACH AND SUMMARY  
OF CONCLUSIONSCONTENTS:

Chapter VII	Assessment of the Practicability of the Interactive Approach: Possibilities and Limitations of its Application
Chapter VIII	Summary of Overall Argument and Conclusions

CHAPTER VIIASSESSMENT OF THE PRACTICABILITY  
OF THE INTERACTIVE APPROACH:Possibilities and Limitations  
of its ApplicationCONTENTS

1. INTRODUCTION
2. A PLIANT STRATEGY FOR MICRO-CLIMATIC  
DESIGN : STAGE 1
3. PEOPLE AND OUTDOOR ENVIRONMENTS
  - 3.1 Physiological Effects
  - 3.2 Mechanical Effects
4. SIMULATION AND PREDICTION OF THE  
BUILDING'S MICRO-CLIMATE
  - 4.1 Insolation and Shading Pattern of Buildings
  - 4.2 Wind Flow Around Buildings
5. THE BUILDING AND ITS MICRO-CLIMATE:  
RESEARCH AND DESIGN
6. SUMMARY AND CONCLUSIONS

## 1. INTRODUCTION

The practical application of the interactive approach is discussed in this Chapter in the light of current and future knowledge, particularly as they relate to the micro-climatic design of buildings, i.e. Stage 1 of the interactive climatic design process (see Chapter 5).

The practicability of this approach is closely linked to our knowledge of the physical conditions which provide comfortable micro-climates and the means of achieving them. There are gaps in the available knowledge concerning the response of people to outdoor climatic conditions. There is also the limited degree of control which we can exert on the micro-climate using buildings and landscape elements as the means of control. Both aspects combined, lead one to adopt a different view of 'comfort' and 'control' in micro-climatic design from that which is currently held to deal with indoor climatic conditions.

We start by exploring 'comfort' and 'control' out-of-doors and discuss, accordingly, the strategy of micro-climatic design and the role of comfort criteria in this connection. We then proceed to review existing criteria for outdoor comfort conditions and point to their limitations. A sample review of prediction and simulation techniques for studying the micro-climate during Stage 1 is also included. We then discuss the importance of gaining knowledge about form/performance relationships which would enhance the application of the interactive approach in design. The use of /

of simulation techniques as a means of generating such knowledge is also indicated.

## 2. A PLIANT STRATEGY FOR MICRO-CLIMATIC DESIGN : STAGE 1

The relationship between indoor climates and the thermal sensations of comfort or discomfort has been studied for many years, and a great deal is known about required comfort conditions indoors (e.g. Bedford, 1961; Humphreys, 1970, 1976; MacFarlane, 1958; Weston, 1959). Normally, the individual characteristics which influence thermal sensation, i.e. clothing and activity, are comparable amongst the major groups of individuals in design (e.g. school children, factory workers, households). Accordingly, concepts such as "general purpose space" and "general purpose temperature" (Humphreys, 1976, p.176) are proposed and used on the assumption of steady-state conditions for the heat exchange between humans and their indoor environments, largely on the grounds of simplicity. Thus by assigning values for those characteristics in a given design we specify the indoor conditions which broadly meet the requirements of thermal comfort. Existing criteria for comfortable conditions indoors are then used in design to make judgements about the climatic performance of buildings and to design heating and other systems.

In principle, there is no difficulty in achieving indoor conditions that depart from the ideal by only a small, and ideally controllable amount. The use of mechanical means of /



of control (e.g. heating, air-conditioning, artificial lighting, etc.) makes it possible to integrate and maintain comfortable conditions all the year around, though a rational use of the energy is necessarily linked to adequate climatic and micro-climatic design of buildings.

Out-of-doors, the situation is different; the man/environment relationship is more complex, and less predictable; we know less about what constitutes adequately comfortable conditions; and a much more limited degree of control is available to us.

The assumption of a steady-state condition is irrelevant. The environment is much more variable in space and time. People are moving from one place to another; they are engaged in a wider variety of activities and dressed in varied clothing. The standardisation of activities and the statistical prediction of the environment and hence any description of general or even typical cases is much more difficult than indoors.

There are gaps in our present knowledge which make existing criteria for 'comfortable' outdoor conditions severely limited and much less decisive in design. (A review of a sample of the work in this area follows in the next section). For example, the "transient response" of people to a changing environment has received little attention (Wyon, 1977). Also, people out-of-doors are exposed to a variety of non-thermal stresses resulting from precipitation, traffic noise, the mechanical effects of the wind, etc., as well as the thermal ones, /

ones, and the combined psychological and physiological effects of these are not known and difficult to study.

There is also the limited degree of control of the micro-climates which buildings and landscape elements can provide. Seasonal changes are much more difficult to deal with and it is usually impossible to provide satisfactory micro-climatic conditions all the year around. But again, the variability or short-term "swings" of natural environments influence people's tolerance and adaptability and make them ready to accept much wider departures from the ideal than they could indoors.

All these aspects impose restrictions on the micro-climatic design of buildings (Stage 1 of the interactive climatic design process; Chapter 5), and lead us to adopt a pliant strategy for appraising the performance of buildings, based on the exercise of relative judgements.

Instead of looking to control the micro-climatic environment within a specific range of conditions as we do, indoors; in micro-climatic design, we should be using the form of buildings to adapt the micro-climate in the spaces around them, so that it is moved from the less comfortable towards the more comfortable - by eliminating extreme conditions and controlling natural variations, and to ensure that no new, adverse conditions are introduced. This will certainly benefit the indoor conditions as well, because it also means reducing the stresses on buildings. But we should also spatially plan the outdoor activities as far as possible in /

in the light of the building's micro-climate in order to increase the probability of achieving comfort where it is most wanted, thus enhancing further the use of the outdoor spaces.

In principle, there would always be a range of alternative solutions available to the architect, influenced also by non-climatic aims or requirements. One can then use the available criteria for satisfactory outdoor conditions, reinforced with common sense, to compare alternative solutions and form relative judgements about their micro-climatic performance. Simulation techniques can be used at this stage to determine which are the better ones, though how much better may be difficult to determine with our present knowledge. In any case, the choice of an acceptable solution is always a matter of design judgement specific to each design and would normally be influenced by the balance between improving the micro-climate and satisfying a range of other aims or requirements.

### 3. PEOPLE AND THE OUTDOOR ENVIRONMENTS

Several attempts have been made to study the effects of outdoor environments on people. These studies are largely confined to the physiological effects on thermal sensation and the mechanical effects of the wind. The following discussion is a critical review of a sample of this work.

#### 3.1 /

### 3.1 Physiological Effects

The thermal sensation of people has been studied in two different ways: empirically, by investigations made on subjects exposed to the natural environment, and theoretically, on the basis of knowledge of the heat balance of the human body.

In 1945, Siple and Passel (as cited by Penwarden, 1973; Lacy, 1977) developed the Wind Chill Index to assess the heat loss from bare, dry skin as a function of air temperature and wind speed (see Fig.1). The index is based on field studies made in the sub-zero conditions of the Antarctic, where the air temperature varied during the investigation from  $-9$  to  $-56^{\circ}\text{C}$ , and the wind speed from zero to  $12\text{ m/s}$  (Penwarden 1973, p.264). Two aspects restrict the use of this index in design: a) It is based on extreme conditions of cold, rarely encountered in most urban areas; b) It relates only to the heat loss from the exposed parts of the human body. A more useful assessment of thermal sensation would necessarily include the heat loss from the clothed parts as well. This work provides useful information on limiting conditions, but the difficulties of extrapolating comfort scales are well known.

Penwarden (1973) relied on a theoretical description of the heat balance of humans to develop charts which represent the cooling effect of the wind as a function of wind speed, air temperature, and clothing (see Fig.2) in normal outdoor conditions in the U.K. However, the use of these charts is also /

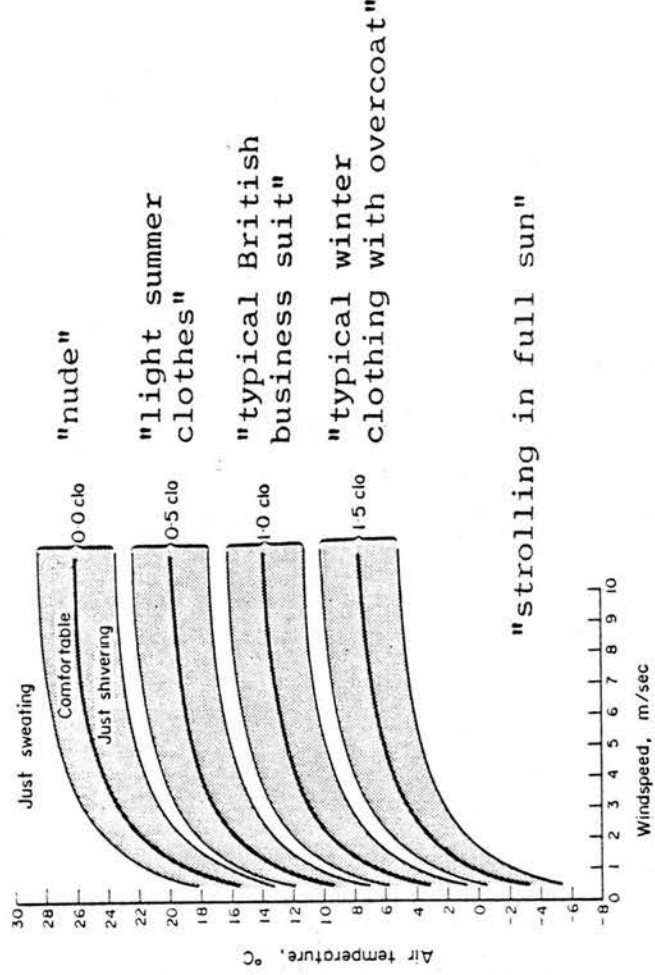


Fig. 1: "Nomogram for calculating wind-chill index..." (from: Lacy, 1977, p.167)

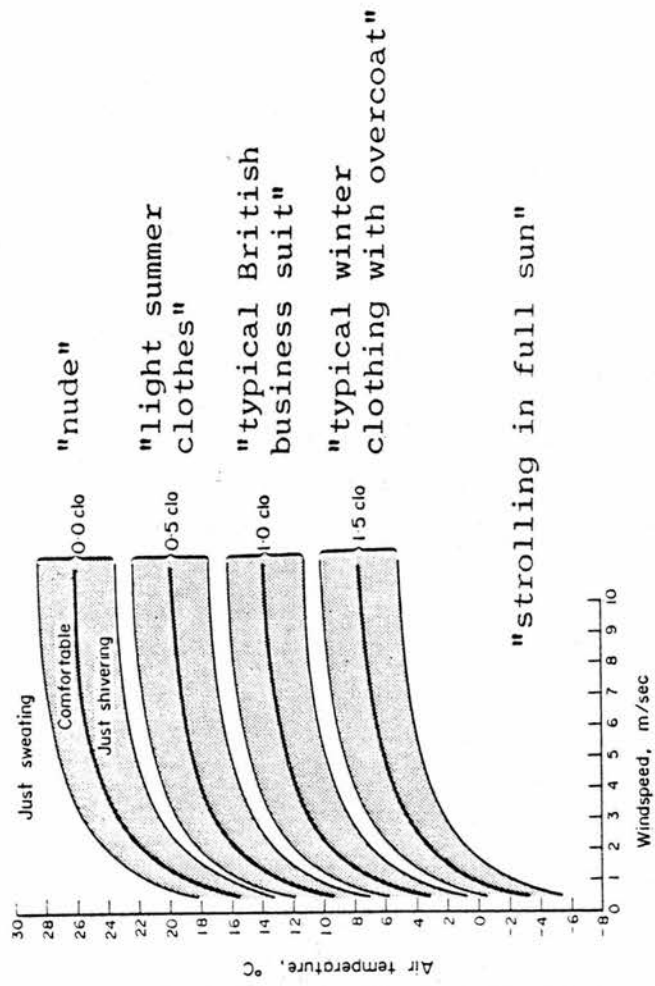
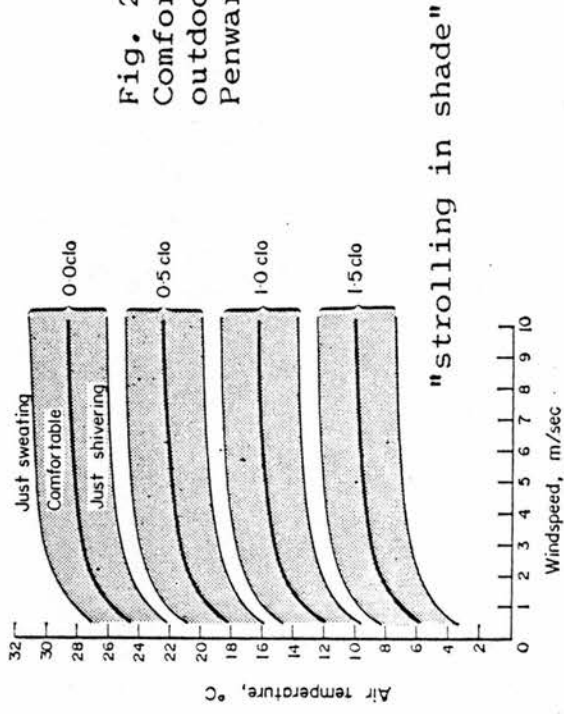


Fig. 2: Comfort conditions outdoor (from: Penwarden, 1973, p.265)





also restricted. Several assumptions had to be made to compensate for the gaps in available information, especially on the insulation value of clothing. Penwarden and Wise (1975, p.41) indicate that the charts are "intended to illustrate the type of relationship which is found to occur, rather than to be used in design".

A thermal index of comfort which is structured independently from clothing and activity levels is the Standard Effective Temperature Index, SET, developed by Gagge et al. (1973). It is a theoretical index combining measures of cold and warmth discomfort, using "skin temperature" and "skin wettedness" as the respective indices. Figure 3 gives an example of "thermal comfort charts", plotted on the basis of print-outs from Gagge et al.'s computer program for the calculation of SET. The charts (in Markus and Morris, 1980, pp. 84-139) cover a wide range of combinations of environmental and personal conditions likely to be found out-of-doors as well as indoors.

However, these charts, as well as Penwarden's charts (Fig. 2) deal with steady-state conditions, and give a description of the instantaneous thermal sensation. The sensation may well be changed with time as a result of transient exposures. In such cases, the duration of people's exposure to outdoor conditions, which is a major component in the description of outdoor activities, must be considered in order to provide adequate description of satisfactory conditions.





### 3.2 Mechanical Effects

In addition to its cooling effect, the wind causes mechanical discomfort and inconvenience to pedestrians in the spaces around buildings, either directly by exerting pressure on the human body or indirectly, due to raising dust, driving rain or snowdrifting. Penwarden and Wise's "Beaufort Land Scale" (see Table 1) gives a reasonable guide on what effects may be observed at different mean wind speeds.

The scale has been used in connection with the results of experimental investigations, to establish limits of acceptability of mean windspeeds for assessing conditions for pedestrians in towns. For example, Table 2 gives Penwarden's limits of acceptability (1973) which take into consideration the results of an investigation made on subjects standing and walking in a wind tunnel, and exposed to steady winds up to 7.5 m/s.

Another study, by Arens (1972), gives a slightly higher mean windspeed than Penwarden's 5 m/s, to represent the onset of discomfort. Arens (ibid, p.II 72) chose 7 to 8 m/s as the threshold value for discomfort; however, his study takes into consideration the results of an experimental investigation he made on subjects exposed to natural, outdoor wind conditions.

The difference between these two limits (Penwarden's and Arens') is not critical, especially since they relate to discomfort "when hair and clothes flap..."; more serious and dangerous effects of wind can occur. But the difference can be /

	Beaufort number	Speed (m/s)	Effects
Calm, light air	0, 1	0-1.5	Calm, no noticeable wind
Light breeze	2	1.6-3.3	Wind felt on face
Gentle Breeze	3	3.4-5.4	Wind extends light flag Hair is disturbed Clothing flaps
Moderate breeze	4	5.5-7.9	Raises dust, dry soil and loose paper Hair disarranged
Fresh breeze	5	8.0-10.7	Force of wind felt on body Drifting snow becomes airborne Limit of agreeable wind on land
Strong breeze	6	10.8-13.8	Umbrellas used with difficulty Hair blown straight Difficult to walk steadily Wind noise on ears unpleasant Windborne snow above head height (blizzard)
Near gale	7	13.9-17.1	Inconvenience felt when walking
Gale	8	17.2-20.7	Generally impedes progress Great difficulty with balance in gusts
Strong gale	9	20.8-24.4	People bown over by gusts

Table 1: Summary of Beaufort Land Scale  
(from: Penwarden & Wise, 1975, p.40)

mean wind speed m/s (10 min.or more)	Description
up to 5	Tolerable
about 10	Unpleasant
10 to 20	Progress is difficult and unsteady
more than 20	Dangerous

Table 2: Limits of acceptability  
of mean wind speeds  
(adapted from: Penwarden, 1973)

be taken to support the argument made earlier that variable, outdoor conditions increases people's degree of tolerance which must be exploited in design to overcome some of the restrictions facing micro-climatic design.

The effects of wind gusts on people can cause greater disturbances than those judged with respect to mean wind-speed, mainly because of the unexpected nature of gusts and their effects on balance in walking. However, the effects of gusts are generally difficult to assess because of the difficulty of studying the turbulence structure of the wind in certain areas. Available information on the response of people to unsteady wind forces (e.g. Penwarden and Wise, 1975; Hunt et al, 1976; Lacy, 1977) suggest that great attention should be given during the design process to the occurrence of high wind speeds (10 m/s or more) because of the high probability of dangerous gusts accompanying them.

In addition to the need for information about people's responses to the gustiness of winds, there is also a need for knowledge about the correlation between the physiological and the mechanical effects of the wind on people. The studies mentioned here relate largely to cold climates in which shelter from the wind is generally desirable. Arens' proposition (1972 p. II 99) in this connection is useful; he chose a mean wind speed of 7 m/s as the "cutoff" limit for thermal comfort - below it, comfort sensation is assumed to be governed by the heat balance of the human body; and above it, the person will be 'uncomfortable' due to the mechanical effects of the wind, regardless of his thermal state.

However, /

However, it is not known in general, how changes in the thermal sensation of a person affects his tolerance of mechanical effects of the wind. This would be useful to know in design, if wind is desirable for its cooling effects as it is in many warm climates. It would be reasonable to assume that people tolerate disturbances in their clothing or hair in warm climates, more than they do in cold ones, if they derive pleasure from the accompanying coolness of the wind. However, in hot-dry conditions there is less need for air movement and the problem of wind-driven dust and sand, such as in the Khamsin in Egypt, can also be critical.

#### 4. SIMULATION AND PREDICTION OF THE BUILDING'S MICRO-CLIMATE

Prediction and evaluation of the building's micro-climate are parts of the appraisal process of building performance in micro-climatic design. There are a number of simulation techniques which are used for this purpose and some are reviewed here. Later (in Section 5) we discuss how by organising research in building/micro-climate interaction we can move some way towards overcoming the difficulties of using simulation techniques in design.

##### 4.1 Insolation and Shading Pattern of Buildings

A number of methods are available for the study of the insolation and shading patterns of buildings.

The /



The "heliodon" is a well-known tool which gives a direct visual indication of the form/sun relationship, using a physical model (see Fig.4). It was originally developed at the Building Research Station by Dufton and Beckett in 1931 (cited by Markus and Morris, 1980, p.401). It consists of an adjustable table representing the building site, which can be tilted and rotated according to the latitude and hour of the day, respectively. The sun is represented by a lamp, sliding up and down a calibrated post indicating the months of the year. The post and the table are kept at a fixed distance from each other (see Fig.5); for the lamp to be reachable by an average person, the distance would be normally about 2 m (ibid, p.403).

Some modifications have been introduced to the original heliodon. The Scottish Development Department introduced the "Shelliodon" (see Fig. 6), in which the model table is mounted on another board which can be adjusted for the months of the year. In this case, the lamp can be positioned further away in order to diminish the errors caused by the table and the lamp being close to one another.

In both cases, however, the model table is adjusted and this requires the observer to view the model from unfamiliar angles. An Australian version of the heliodon, termed "Solarscope" (see Fig. 7) overcomes this limitation. In this device, the model remains stationary on a horizontal board that neither tilts nor rotates. A controlled arm, containing the light source, revolves about the board according /



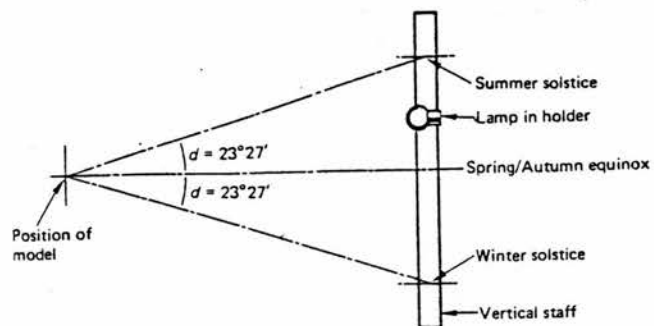


Fig.5: Arrangement for heliodes (from: Markus and Morris, 1980, p.403)

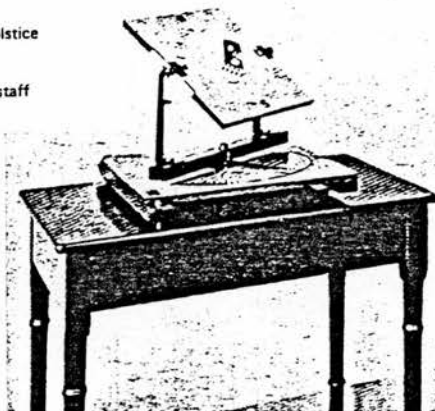


Fig.4: The heliodes (from: Aronin, 1953, p.40)

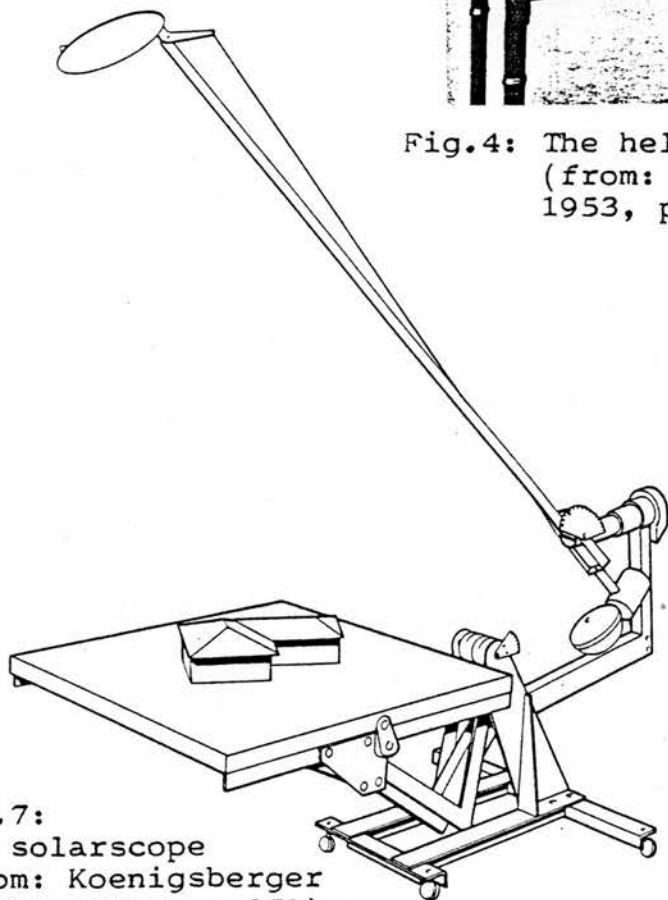


Fig.7: The solarscope (from: Koenigsberger et al., 1974, p.270)



Fig.6: The shelliodon (from: Markus and Morris, 1980, p.405)

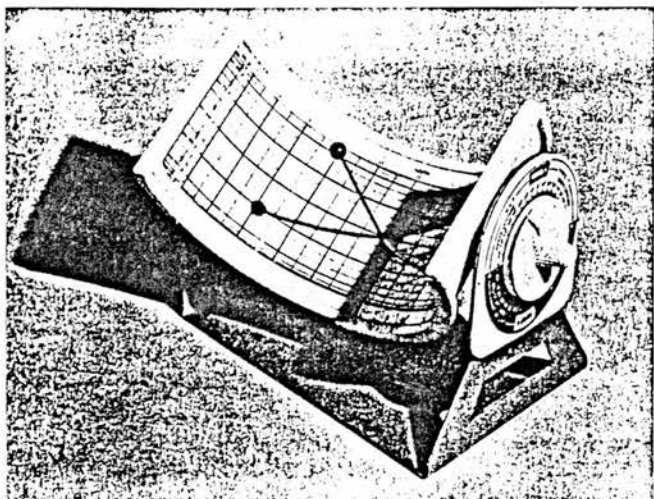
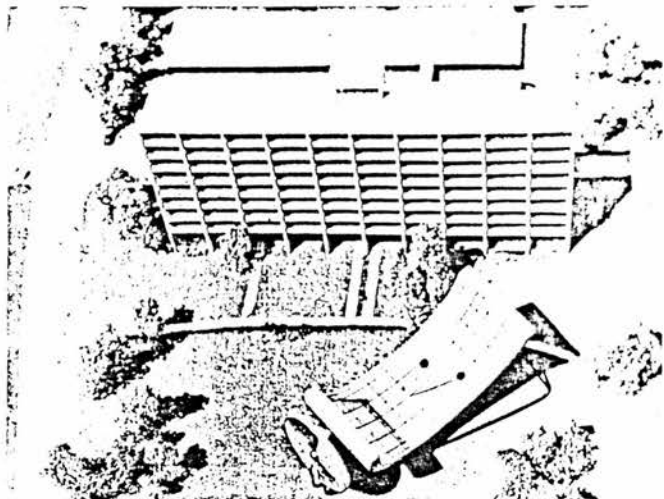


Fig.8: The shade-dial (from: Olgyay and Olgyay, 1957, p. 29)



according to settings for latitude, season and time of day.

Olgyay and Olgyay (1957) developed another device, termed "shade-dial" (see Fig. 8); it works on the principle of a sun-dial but instead of measuring time it indicates the sun's position in the sky. The device consists of a semicircular dial with a small ball positioned at its centre. The dial is calibrated for seasonal and hourly conditions; when illuminated the position of the sun corresponds to the position of the shadow of the ball on the dial. By placing the dial near to a model, and orienting them together in front of a light source (which can be the natural sun) one can reproduce the form/sun relationships for a given month and hour of the day, and the model will be illuminated accordingly.

All these techniques involve testing physical models of built forms. Stereographic projection (Olgyay and Olgyay, 1957; Koenigsberger et al, 1974) is a different technique which relies on graphical description of the form/micro-sun relationship. In this technique, the shading pattern of a building or group of buildings is drawn, point by point, using "solar charts" or "sun-path diagrams" to determine the sun's movement and a "shadow angle protractor" to determine the "shading mask" of the form as seen from a particular point of observation. The technique is useful in designing shading devices, but it is tedious and cumbersome when used to study the shading pattern of buildings.

4.1.01 Computer-based simulation techniques overcome the limitations of models and the amount of calculation of graphic methods by providing rapid and simple means of investigation and the possibility of answering more complex questions. Smith and Wilson (1976) developed a computer program, SHADE, for "determining the time-average distribution of shading due to any ensemble of forms over any prescribed period" (ibid, p. 187). The use of the program is simple; it requires the user to specify:

- (i) a simplified description of the site;
- (ii) the span of hours and days over which the shading is to be predicted;
- (iii) the forms casting the shadow;
- (iv) particular periods within the maximum defined in item (ii) for which data is required.

An example of the program's output is given in Figure 9, showing the average distribution of shading over a specified period of the day and the year in the form of a contour map of ten levels of intensity, from total exposure to the sun to total shade.

#### 4.2 Wind Flow Around Buildings

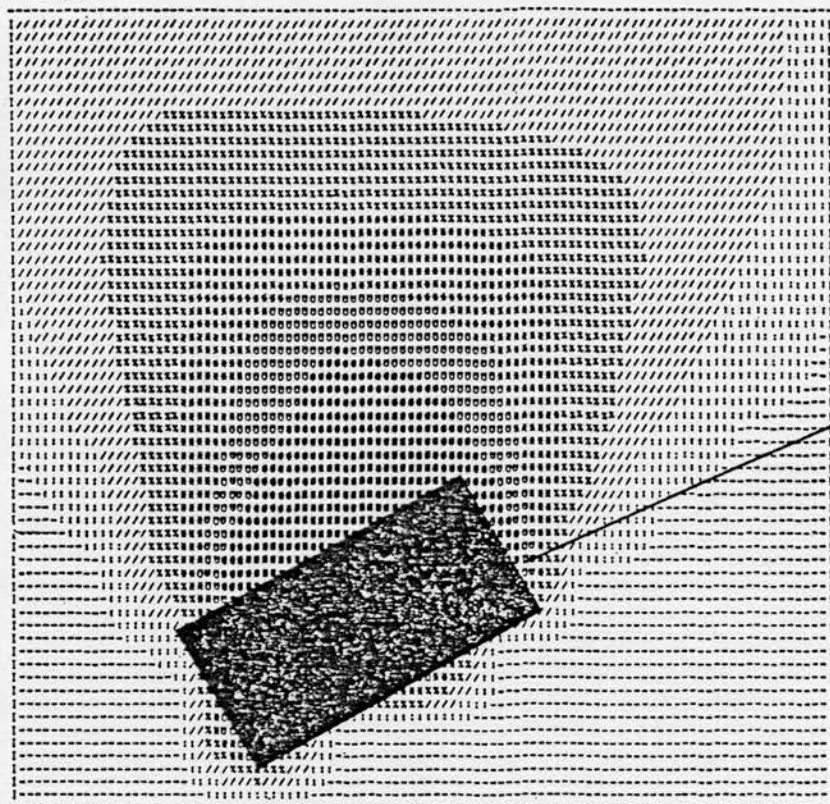
Testing physical models in a wind tunnel is still the only technique which is readily available for studying the wind flow in the spaces around and between buildings during the design process; though efforts are being made to develop new techniques based on computer simulation.

Figure /

## AVERAGE SHADING DISTRIBUTION MAP...

PERCENTAGE AVERAGE SHADING FROM 1-JAN TO 30-JAN BETWEEN THE HOURS 0700 AND 1800  
 BOX MEASURES 20.00 BY 20.00 UNITS IN X AND Y DIRECTIONS RESPECTIVELY

N  
 NNN  
 NNNNN  
 N  
 N NORTH  
 N  
 N



## KEY TO SYMBOLS

REPRESENTS 0 TO 10 PERCENT SHADING  
 . REPRESENTS 10 TO 20 PERCENT SHADING  
 - REPRESENTS 20 TO 30 PERCENT SHADING  
 | REPRESENTS 30 TO 40 PERCENT SHADING  
 / REPRESENTS 40 TO 50 PERCENT SHADING  
 \ REPRESENTS 50 TO 60 PERCENT SHADING  
 # REPRESENTS 60 TO 70 PERCENT SHADING  
 0 REPRESENTS 70 TO 80 PERCENT SHADING  
 8 REPRESENTS 80 TO 90 PERCENT SHADING  
 9 REPRESENTS 90 TO 100 PERCENT SHADING

Fig. 9: Example of computer output of average shading distribution (from: Smith and Wilson, 1976, p. 194).



Figure 10 shows an example of a "boundary layer" wind tunnel (Cook, 1975). It consists of three main parts: the "inlet box" which is responsible for making the incoming wind symmetrical; the outlet fan or "fan volute", equipped to control the wind speed; and a "working section".

The working section is made of three areas: a "flow processing section" accommodating various combinations of screens; a "plain working section" to accommodate the necessary elements of surface roughness. These two sections are /

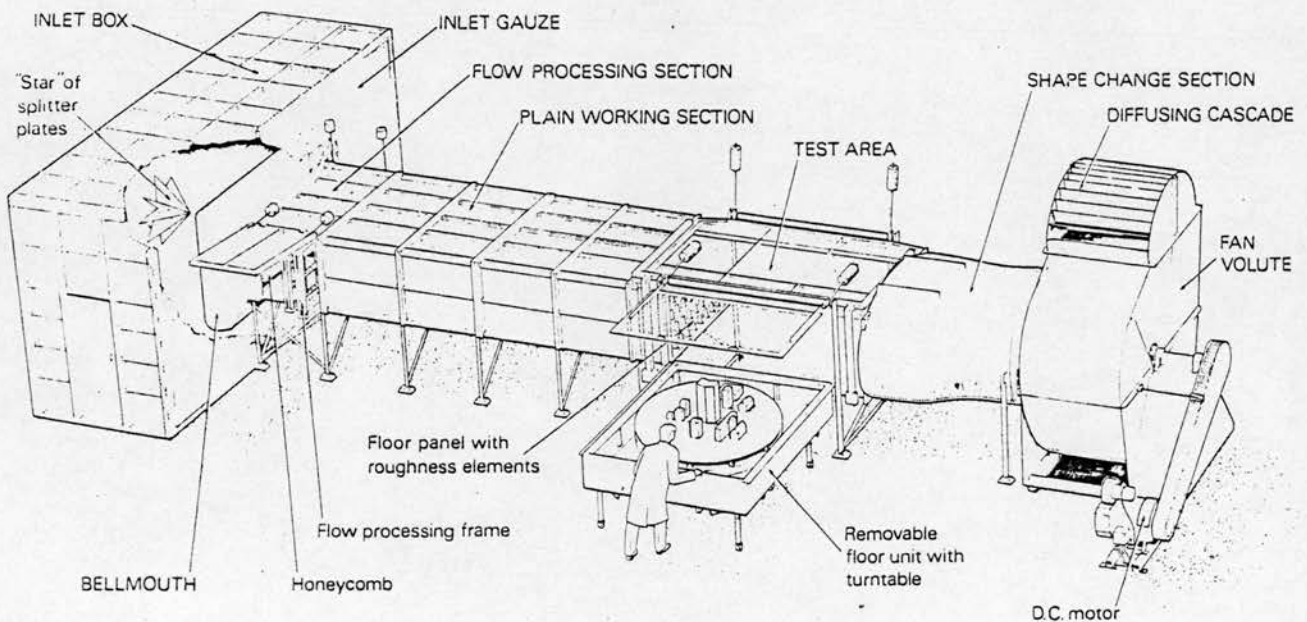


Fig. 10: Example of boundary layer wind tunnel (from: Cook, 1975, p. 15)

are responsible for reproducing the required profile and turbulence characteristics of the incoming wind. The remaining area is the main "test area" for accommodating the model. The test area is accessible from either side of the tunnel and glazed for visual observation. The floor of this area is removable and can be exchanged for alternative floor units, with turntable for controlling the orientation of the model relative to the wind.

Different methods of flow visualisation and measurement techniques are used in connection with wind tunnel investigations and are described in a number of places (e.g. Sexton, 1965; Griggs and Sexton, 1974; Penwarden and Wise, 1975).

4.2.01 The computer simulation of wind flow around buildings has also attracted research interest. Hanson et al (1982)<sup>1</sup> report on a research project currently being undertaken to develop a computer program for predicting the flow around built forms. The development of this or similar programs must be seen as advantageous, technically as well as economically. The flexibility and speed of computer modelling, coupled with the fact that computers in general are rapidly getting cheaper, should eventually enable even small design offices to pay greater attention to the study of micro-wind conditions during the design process.

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1. See also Hanson and Summers, 1982.



5. THE BUILDING AND ITS MICRO-CLIMATE:  
RESEARCH AND DESIGN

The particular knowledge of building performance that is required in design application is critically dependent on the stage at which it is applied. The analysis of the interactive climatic design process (Chapter 5) showed that, in Stage 1, the architect studies the micro-climatic performance of a range of potential building solutions before accepting one, or converging them into an acceptable solution. Relative judgements of performance, as discussed in the previous section are a practical necessity for decision-making at this stage. The use of simulation techniques should certainly enable the architect to perform such a task.

Basically, there are two types of simulation involved - 'crude' and 'refined'.<sup>1</sup> Crude simulations are needed when studying design concepts and when details are not critical to decision-making. Simple forms can be used to embody the geometry of built forms and major landscape elements in crude simulation. Refined simulations are resorted to when data is needed and the detailed examination of a particular design is critical. A more sophisticated embodiment of form would necessarily include in this case details of architectural features such as shading devices, balconies, canopies, etc.

The /

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1. See Figure 12 in this Chapter.

The use of simulation techniques, however, encounters difficulties: time, cost, availability and accuracy are easily identified. The introduction of computer simulations will surely be an advantage. But is it true to say that the architect should always rely on simulation techniques to study the micro-climate and the building performance, each time a form is investigated? The answer is certainly in the negative. Such techniques are used essentially as evaluative tools, though used early on in the design process they can generate ideas about appropriate forms. However, using them as generative tools may well be costly and time-consuming. The question then arises as to how to guide the decision-making process and reduce the need for using simulation techniques to a minimum?

This of course touches upon the way potential solutions are identified. The argument is: sufficient knowledge of the relationship between built form and its performance, in terms of the sort of micro-climate it produces, should be part of our preconceptions that strongly influence the identification of potential solutions.<sup>1</sup> Knowledge of form/performance relationship operates through a process of elimination, mentally or otherwise, as a guide for design. The more we know about how micro-climatic performance and form are related, i.e. how changes in the parameters of built form /

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1. Helmy (1978) introduces a "generative" approach to climatic design based on the use of knowledge of form/performance relationships to generate acceptable forms. However, her proposals are concerned primarily with the control of indoor climates.

form (height, aspect ratios, spacing, etc.) affect the variables of the form's micro-climate (especially wind-flow and solar radiation distribution) the less we need to involve ourselves in 'trial-and-error', and thus the less we rely on simulation techniques in design in order to determine acceptable forms.

The development of such knowledge is the task of "morphological" studies in building micro-climatology. Several studies have been made to explore the micro-climatic performance of built forms in a systematic way. For example, Smith and Wilson (1976) investigated the pattern of airflow within a rectangular space, enclosed by a wall. The geometry of the enclosed area was varied systematically during the investigation in terms of the ratios of plan dimensions, with constant height of wall. Figure 11 shows the characteristic changes of the flow as a function of geometry.<sup>1</sup> Other studies have developed mathematical models describing the interaction between solar radiation and form which can be used to generate knowledge about the distribution of solar radiation in outdoor spaces as a function of the geometry of courtyards (Mohsen, 1978) and urban built forms (Numan, 1977).

The relationship between these or similar morphological studies /

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1. See also Hassan, 1974, and Soliman, 1976 who deal with the form/micro-wind interaction systematically.

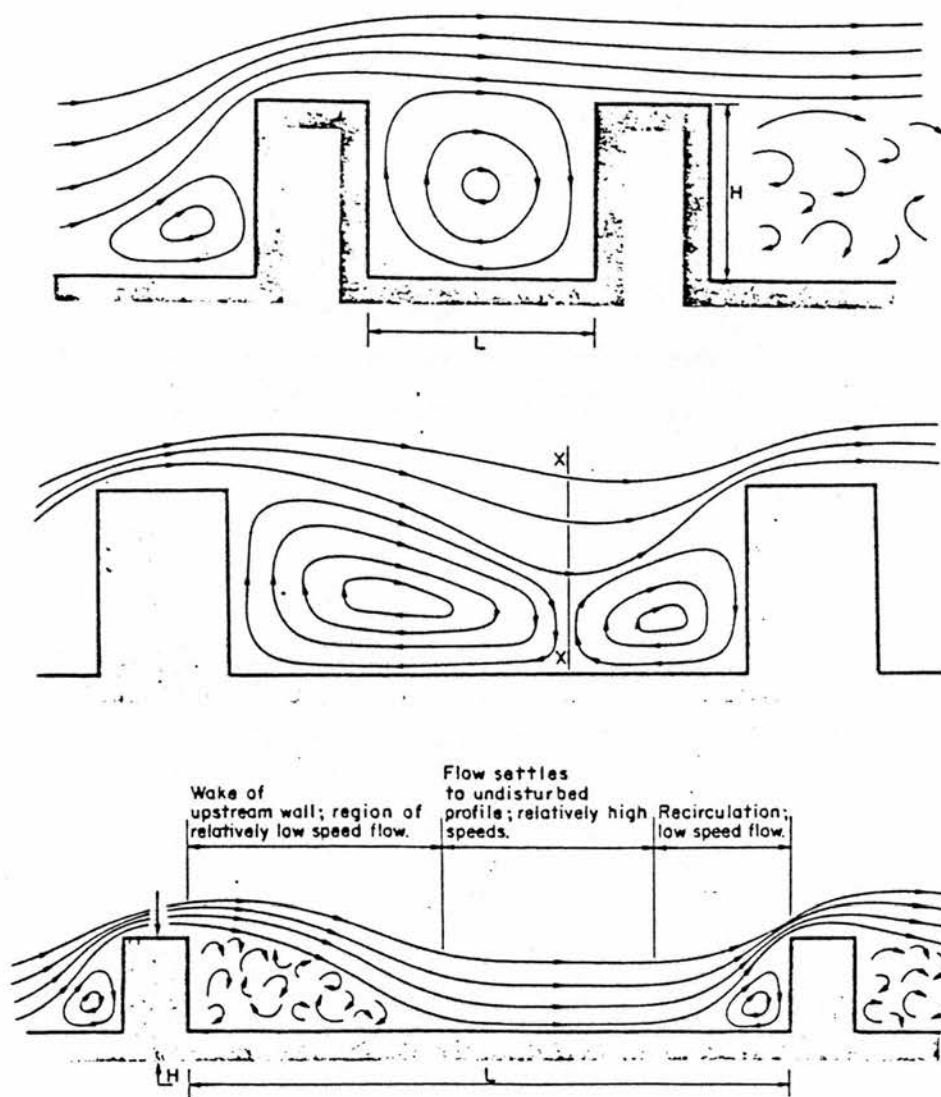


Fig. 11: Characteristic changes in airflow as a function of geometry (from: Smith and Wilson, 1977, p. 226, p. 228 and p. 227).

studies and micro-climatic design, in particular the identification of potential solutions, is portrayed schematically in Figure 12. It shows how knowledge of form/performance relationships provides the link between Research and Design in this connection. It also shows that the two types of simulation, crude and refined, have different roles /

Stage 1  
(of the Interactive  
Climatic Design Process)

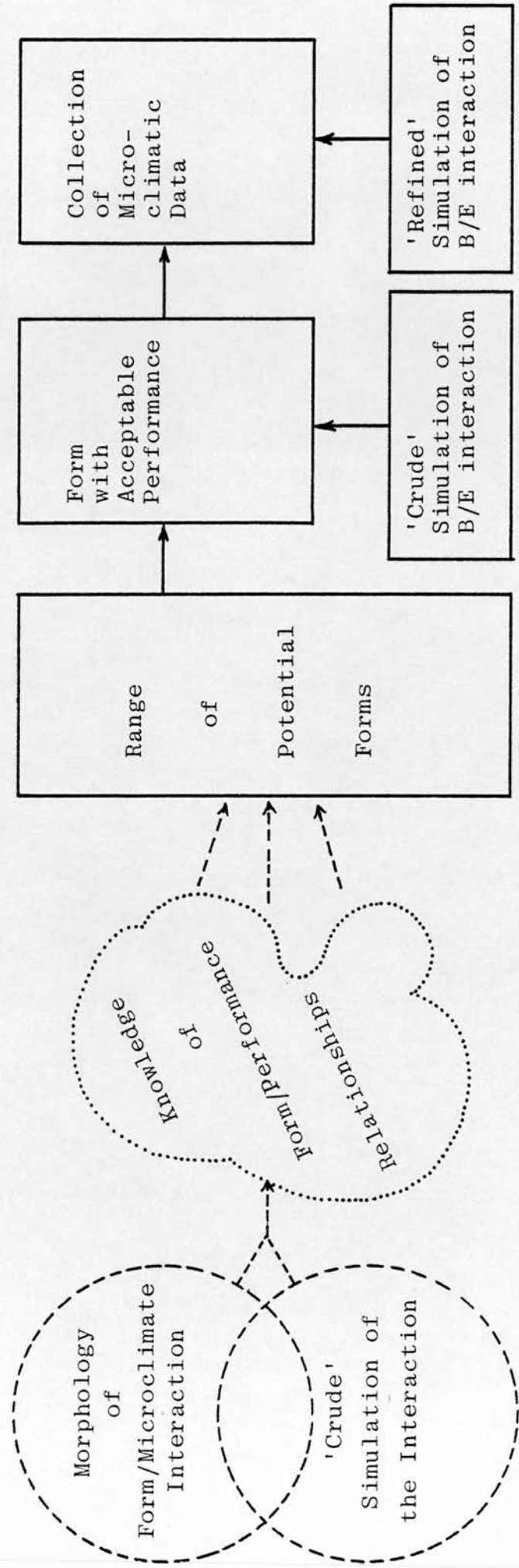


Fig.12 : The use of Simulation Techniques in Micro-climatic Research and Design



roles to play in both research and design. Wilson (1982) argues the case for computer simulations which would be of great advantage to the accomplishment of morphological studies, and to the adequate micro-climatic planning and design of buildings.

Available knowledge about the form/micro-climatic performance relationships, however, lacks an overall coherence; there is a need, for example, for comprehensive study of form/micro-wind interaction, investigating the full range of morphological parameters, sharing common descriptors of form and common measures of performance. Adequate criteria for satisfactory micro-climates are essential for such investigation to be of any use in design, because they would indicate which ranges of parameters are likely to lead to 'good' or 'bad' performance in specific climates.

There is also the need to study the mutual relations of air movement and temperature as a function of the planning of the shading patterns of buildings. For example, most of the studies which deal with layouts and their effects on natural ventilation inside buildings (e.g. Soliman, 1976) are concerned with wind-induced ventilation and its dependence on the pressure distribution around and on buildings, as a function of the geometry or density of built form. However, local thermal currents or "breezes" which are particularly desirable in warm climates, are influenced by pressure differences caused by differences in temperature. The shading pattern of buildings, especially in hot-dry climates, plays /



plays a major role in controlling pressure differences; little is known to help the architect in utilizing shading patterns to control the thermal currents in the immediate vicinity of buildings. Such investigations would be extremely difficult to carry out using analogue techniques because of the scaling problems; however, the development of computer simulation might eventually make possible the investigation of this problem.

## 6. SUMMARY AND CONCLUSIONS

Given the gaps in the available information about comfortable outdoor environments, the variability of these environments, and the limited degree of control of micro-climates which buildings can provide, it is necessary for the practical application of the interactive approach to adopt a strategy for micro-climatic design which would make use of the value of relative judgements. Available criteria for comfortable outdoor conditions (though limited) can be used to compare potential solutions and determine the better.

The difficulty of using simulation techniques in micro-climatic design emphasizes the value of systematic investigations of form/performance relationships in order to develop knowledge about the performance characteristics of built forms in terms of the sort of micro-climates they produce. Such knowledge could then be used in design to generate acceptable forms at an early stage.

CHAPTER VIIISUMMARY OF OVERALL  
ARGUMENT AND CONCLUSIONS

## SUMMARY OF OVERALL ARGUMENT AND CONCLUSIONS

The philosophical and methodological arguments of this thesis are governed by the fact that the climatic environment in which the building is embedded (i.e. the micro-climate around the building and the indoor climate) is a dependent phenomenon, readily influenced by the building itself, or more precisely by its design.

One of the functions of a building is to provide satisfactory indoor climate for human habitation and activities. Due to its mere existence, however, the building creates a micro-climate in its immediate vicinity. This micro-climate depends on the design of the built form. Furthermore, it is this micro-climate which the building has to modify so as to produce the indoor climate (see Chapter 4).

The argument is, then, for buildings to be designed so as to produce satisfactory conditions of micro-climate as well as indoor climate. The significance of the micro-climate of buildings is twofold: it affects the well-being of people out-of-doors and influences their activities, and it controls the environmental stress on the building. An ideal micro-climate would, therefore, satisfy the relationship between these two kinds of effects. Lack of knowledge in this field leads us to follow the practical assumption that a satisfactory micro-climate for people, nearer to their bioclimatic needs than the local climate, not only enhances the amenities of the outdoor spaces but also improves the climatic performance of the buildings which produce this micro-climate /

micro-climate by reducing the environmental stresses on them.

A number of points develop from this approach. Some are philosophical, relating to the range of factors which should properly be taken account of in designing an adequate built environment; others are methodological, concerning the structure of the design process.

There exists a tendency in the contemporary practice of architecture to separate the environmental problems of outdoors from those of the indoors, by underestimating the former and dealing primarily with the latter. This encourages (or may be a response to) a piecemeal approach to design whereby buildings are dealt with in isolation from their surroundings, climatically or otherwise. The outdoor spaces between and around built forms tend to become "left-over" spaces to be dealt with separately, rather than being conceived as an inseparable part of the built environment. The separation between indoors and outdoors of the built environment though artificial has been institutionalised in the separate identities which are given to architects, landscape architects, and urban designers and which are emphasised by their separate academic training. This, inevitably, leads to loss of insight into the totality of the built environment which results in disadvantageous effects on, using Fitch's words (1972, p. 178) the "experiential reality" of the built environment. The conventional approach to climatic design (see Chapter 2) contributes to this loss by offering a 'linear' design /

design strategy that is not aimed at designing buildings in relation to their micro-climates.

"Independent" and "dependent" variables in design provide a useful conceptual basis for ordering decision-making during the design process (see Chapter 5). However, the over-emphasised indoor/outdoor separation distorts the value of this concept. For example, there is a tendency to regard the problems of the outdoors as 'independent', lying outside the sphere of influence of design so that they can influence the 'solution' only as long as they are included in the data of the 'problem'. The analysis in Chapter 5 showed that this need not necessarily be the case, at least as far as the climatic design of buildings is concerned. It showed that the micro-climate is a dependent variable at an early stage of the design process and, more important, that it becomes an independent variable at the following stage. This flow of information makes it meaningless to separate the 'problem' from the 'solution' in building design. In the second edition of his book on design methods, Jones (1981) reviewed a number of "new topics", directly linked to design methods. One of these topics is the "Interdependency of Problem and Solution". Jones argues that: "To think of designing as 'problem-solving' is to use a rather dead metaphor for a lively process..." (ibid, p.xxiii). What is more, as T.V. Lawson (1980, p. 210) argues, "... the format and content of the data which [the design] demands changes during the lifetime of the design process". Consequently, an adequate design strategy would incorporate both 'prediction' /



'prediction' and 'response'. This argument strongly influences the structure of the design process and forms the basis of the interactive approach to climatic and micro-climatic design, proposed in this thesis.

The synthesis of the built form in this approach is a process of successive approximation, in which the form evolves in two stages (see Chapter 5). Stage 1 deals with the control of the micro-climate through the design of the building's shape. The design of the fabric is then dealt with in Stage 2 so as to control the indoor climate on the basis of knowledge of the micro-climate. Prediction, evaluation, and the response to the micro-climate is essential in this process. Design is extended to include the spatial relationship between the form under consideration and the form of the surroundings; that is, to the design of the outdoor spaces, the "anti-form". Knowledge of this relationship is necessary for adequate prediction of the climatic performance of buildings (see Chapter 4).

The practical application of this interactive approach is dependent on the prediction, during design, of the building's micro-climate. A number of simulation and prediction techniques can be used in this connection (see Chapter 7). However, prescribed knowledge of form/micro-climatic performance relationship i.e. the relationship between a form and its performance in terms of the sort of micro-climate it produces in specific climates, can be applied early on in design so as to guide the generation of range of acceptable forms. /



forms. Computer simulations of form/micro-climate interaction provide speed and flexibility and would be of great advantage both for the development of such knowledge and for use in design to study a particular interaction in the context of a given design problem.

The case for the interactive approach has been argued for in this study on a theoretical basis. Although empirically-derived information relating to the building micro-climates has been referred to at various points (see Chapters 3 and 7) further development and research are needed to provide empirical support for the value and practicability of the approach to design proposed in the thesis.

The philosophical and methodological aspects of the interactive approach are logical developments, made on the basis of the structural analysis of the building/environment interaction (see Chapter 4). Nevertheless, the thesis lacks the support of case studies. The limitations of the time-scale of a Ph.D. thesis is the prime reason behind their omission.

Two types of research might support the thesis. The first is illustrated by the work of Penwarden and Wise (1975). Such investigations would analyse different arrangements of built forms in an attempt to evaluate their micro-climates as a function of form. The second, illustrated by Kenworthy (1978, 1980) would systematically investigate the relationships between indoor conditions, micro-climate and form, treating micro-climate as a product of the form.

Ultimately, /

Ultimately, however, the only satisfactory test of the method which has been proposed would be its application in the design of real buildings; but to attempt to make such a test objective, would raise all the familiar and perhaps insoluble problems associated with comparing and evaluating different methods of design.

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